FOOD QUALITY AND PROPERTIES OF QUALITY PROTEIN MAIZE

A Thesis

by

ANA MARIA LEAL DIAZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Food Science and Technology

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ABSTRACT

Food Quality and Properties of Quality Protein Maize.

(December 2003)

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Quality protein maize (QPM), high protein corn (HPC) and food grade maize (FGM) were processed into tortillas and direct expanded extruded snacks. QPM had similar test weight, density and kernel size with 45% more lysine and 38% more tryptophan compared to FGM. HPC had the largest kernel with density and test weight similar to FGM.

During alkaline cooking, HPC absorbed water faster than QPM and FGM. White QPM required shorter cooking time and had less dry matter losses compared to FGM. All corn varieties had excellent pericarp removal at the optimum cooking time. Tortillas from QPM had better pliability and rollability after storage compared to FGM and HPC. HPC tortillas had lower rupture force after storage. The use of QPM for tortilla production may reduce energy and sewage cost, and could produce a tortilla with longer shelf stability with improved nutritional value.

Decorticated and non-decorticated QPM, FGM and HPC grain were processed into corn meal and direct expanded snacks. A modified short scale dry milling system was used to produce the corn meal. QPM produced more coarse meal with greater fat content compared to FGM. Decortication decreased fiber content and coarse meal yield. Non-decorticated meal had greater protein, fiber and fat content compared to decorticated meal. The modified short flow milling system provides reduced lost fractions for extrusion into nutritionally improved products.

Extrusion was performed in a low cost friction extruder. QPM extruded faster than FGM and HPC. FGM required greater specific mechanical energy than QPM. Extrudates from FGM were the most expanded followed by QPM and HPC. Extrudates from the three corn varieties were acceptable to the panelists and decortication did not affect acceptability. The improved nutritional value of QPM, was retained during dry milling and extrusion.

Current QPM varieties can be processed into tortillas with longer shelf stability and meal for extrusion into a wide variety of snacks and other foods. These may have application in specialty health foods and in developing countries where maize is a staple food.

DEDICATION

This thesis is dedicated to my parents Ana Diaz and Raymundo Leal for all their love, encouragement and support.

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CHAPTER I
INTRODUCTION

The tragedy of hunger is still a reality in today's world. In every country, there are groups of people who cannot realize their full human potential, either because their diets are inadequate or, because of sickness, their bodies are unable to benefit fully from the food they consume. According to FAO, there are 800 million people in the world who do not have enough to eat to supply their basic energy needs (FAO 2001).

Cereals supply more than one half of the energy consumed by the people in the world and nearly one half of the protein. More than half of the world’s malnourished children live in countries where maize is an important food. Maize is the cereal of major importance in the developing world and has the highest genetic yield potential of all the cereal grains (CIMMYT 2001). In the year 2002, corn was the leading cereal crop with 29.7% of the world cereal production followed by rice and wheat (FAOSTAT 2003).

Maize protein has deficiencies of lysine and tryptophan and excess of leucine, leading to poor growth and kwashiorkor in young children and pellagra in adults. Forty years ago Mertz and his associates reported that the opaque-2 gene increased the content of lysine and tryptophan and decreased leucine (Mertz et al. 1964). Agricultural use of opaque-2 was limited due to lower yield and poor kernel characteristics. Intensive breeding programs at the International Maize and Wheat Improvement Center (CIMMYT) transformed opaque-2 into varieties with higher yields, improved nutritional value and good kernel characteristics and called it quality protein maize.

Maize is used in a wide variety of products around the world such as tortillas, tortilla chips, taco shells, and others. Tortillas are a flat bread made from either corn or wheat. In 2002, U.S. tortilla sales at wholesale prices were more than $5 billion,

This thesis follows the style and format of Cereal Chemistry.

representing a growth rate of 57% from 1996 to 2002 (TIA 2003). Worldwide the snack industry is becoming larger and more important every day. Savory snack sales in United States increased from $18.1 Billion dollars in 1998 to $20.6 in 2000, extruded snacks accounted for more than $2 Billion in 2000, according to the Snack Food Association.

Within the improvement of quality protein maize varieties, there is a need to compare the products made from new varieties and made from normal corn. The goal of this research was to evaluate the usefulness of quality protein maize in alkaline cooked and direct expanded products.

The objectives of this study:

1. Evaluate kernel characteristics of quality protein maize, high protein corn and food grade maize.
2. Compare alkaline cooking properties of quality protein maize, high protein corn and food grade maize.
3. Evaluate direct expanded extruded snacks from decorticated and non-decorticated quality protein maize, high protein corn and food grade maize.

CHAPTER II
LITERATURE REVIEW

The importance of maize

Corn originated in central Mexico about 7000 years ago, starting from teosinte (*Zea mays parviglumis*) which was domesticated. Maize (*Zea mays*) was essential in Mayan and Aztec civilizations. The oldest maize was found in Teotihuacan, a valley near Mexico city (FAO 1992).

The three principle uses of corn are: as food, as feed for livestock and as raw material for industry. The forms of maize consumed around the world vary, ranging from cooked immature grain to processed shelled kernels (Bressani 1991).

A crop of maize is harvested somewhere around the world every month of the year (Mangelsdorf and Reeves 1939). In the year 2002, corn was the leading cereal crop with 29.7% of the world cereal production followed by rice (28.5%) and wheat (27.9%) (FAOSTAT 2003). The maize production leader in 2002 was United States with 39% of world production, followed by China with 18.6%. Specialty corns such as popcorn, sweet corn, high-protein corn, waxy corn, high oil corn, and others, account for less than 5% of the total U.S. corn production; individually each has less than 1% (Boyer and Hannah 2001).

Nutritional value of maize

Maize in its different processed forms is an important food for large numbers of people in the developing world, providing significant amounts of calories and protein. In 1984, Food and Agriculture Organization (FAO) reported that 22 of 145 countries consume more than 100 g of maize per person per day. Maize is staple food in some Latin American countries, particularly Mexico and Central America, as well as countries in Africa.

Poor nutritional value of maize grain has been well known for a long time (Osborne and Mendel 1914). Maize has a low protein concentration with protein quality limited by deficiencies in lysine and tryptophan and has an excess of leucine which suppresses utilization of isoleucine, leading to a poor growth and kwashiorkor in children and pellagra in adults (Mertz et al. 1964, Graham et al. 1990).

The need to improve the nutritional value of maize has been recognized for a long time (Osborne and Mendel 1914). Genetic improvement of nutritional value cannot tolerate a yield penalty, which is often difficult to overcome (Vasal 2001).

Maize proteins

Protein quality in corn depends on the amount and balance of the essential amino acids (Bressani 1991). Proteins with high biological value have a lysine: tryptophan (L/T) ratio of 5-8 by weight (Flodin 1997). Protein quality of maize is similar to wheat or sorghum but lower than opaque-2 maize and quality protein maize (QPM) (Table I).

TABLE I
Protein Quality of Maize and Other Cereals

Cereal	Protein quality[a] (% casein)	Lysine[b] (g / 100 g protein)	Tryptophan[b] (g / 100 g protein)
Regular maize	32.1	2.90 [c]	0.51 [c]
Opaque-2 maize	96.8	4.00 [c]	0.70 [c]
Quality protein maize (QPM)	82.1	4.13 [d]	0.97 [d]
Rice	79.3	3.69	1.15
Wheat	38.1	2.79	1.28
Sorghum	32.5	2.24	1.20
Oats	59.0	4.51	3.61

[a] FAO (1992).
[b] Lasztity (1996).
[c] Graham et al. (1980).
[d] Ortega et al. (1986).

Proteins of the corn kernel are traditionally classified by solubility in different solvents. The prolamines of corn, called zein, are soluble in alcohol with or without a reducing agent and comprise about 52% of the kernel nitrogen. Glutelins are soluble in dilute alkali and comprise approximately 25% of the kernel nitrogen, albumins are soluble in water and comprise about 7% while globulins are soluble in salt solution and comprise about 5% of the kernel nitrogen (Boyer and Hannah 2001). The major protein, zein, has poor nutritional quality. Zein contains large amounts of glutamine, proline, and alanine, leucine (FAO 1992) and reduced lysine content (0.1 g/100 g of protein). Glutelin, on the other hand, is higher in lysine content (2-3 g /100 g of protein) (Vasal 2001).

The distributions of weight and nitrogen among parts of the kernel for high protein corn, quality protein maize and regular maize are shown in Table II. In the mature corn kernel, the two principal sources of protein are the germ and endosperm. The germ protein is superior both in quality and quantity and is composed of 60% albumin and 5-10% zein. Normal endosperm protein content decreases from the

TABLE II
Distribution of Weight and Nitrogen Among Parts of the Corn Kernel[a]

Maize Sample	**TKW [b]**	**Weight distribution**		**Total N[c]**	**Nitrogen distribution**	
	(g)	**Endosperm**	**Germ**	**(%)**	**Endosperm**	**Germ**
US high protein (H5)	216.0	82.7	10.4	2.24	83.2	14.6
US high protein (HP)	248.5	78.9	13.7	2.14	78.2	19.1
Nutrica QPM	295.5	82.7	11.6	1.42	72.8	25.5
Yellow QPM	324.5	81.6	12.5	1.48	73.4	24.2
White QPM	265.5	82.4	11.7	1.36	72.8	25.7

[a] FAO (1992).
[b] Thousand kernel weight
[c] Nitrogen

periphery inward, and is composed of 3% albumins, 3% globulins, 60% zein and 34% glutelin (Vasal 2001).

Importance of lysine and tryptophan

Lysine and tryptophan are essential amino acids for humans and monogastric animals and have to be supplied by the diet. Of all the essential amino acids, lysine is the most strongly conserved in humans (Flodin 1997). L-lysine has a positive effect on Ca metabolism in humans. Studies in animals and humans have shown that dietary supplements with L-lysine can increase intestinal calcium absorption and prevents an increase in Ca excretion in the urine after Ca load (Civitelli et al. 1992). It is also involved in the cross-linking process of bone collagen and in the biosynthesis of carnitine and elastin (Flodin 1997). Therefore the addition of lysine into a lysine deficient diet will improve bone health in children and postmenopausal woman.

Triptophan is required for the production of niacin thus helping to combat pellagra. It is used by the human body to produce serotonin, a major neurotransmitter that is important for normal nerve and brain function. Serotonin is involved in the control of mood, aggression, pain, anxiety, sleep, memory, eating behavior, addictive behavior, temperature control, endocrine regulation, and motor behavior (Sandik 1992).

High protein corn

Attempts to increase protein content in corn started in the last part of the 19th century producing strains with protein levels up to 27% on weight basis (Vasal 2001), and is mainly determined by the protein in the endosperm (Dudley et al. 1977). Ninety generation of selection for protein concentration in the maize kernel were completed in 1989 in the Illinois High Protein Corn, the additional progress since generation 76 was approximately 4 σ_a (Dudley and Lambert, 1992). The endosperm of this type of corn has mostly horny cells densely packed with protein. In addition, this type of corn has a layer made of one to two cells adjacent to the aleurone layer, which contain mainly protein (Wolf et al. 1969). Protein quality remains unaltered due to an increase in total zein content, which is deficient in lysine and tryptophan (Bhatnagar 2001), which means, the improvement is in protein quantity and not protein quality. There is a strong negative correlation between protein content and grain yield (Dudley et al. 1977, Glover 1992,).

Wilson Genetics in Harlan, IA, developed the white hybrid Zimmeran 1851 W through traditional breeding methods. It produces grain yields comparable to or better than standard yellow dent corn. It yields 1-2 % more protein, and the resulting starch has 50% amylose and 50% amylopectin, while regular corn has 25% amylose and 75% amylopectin (Strissel and Stiefel 2002).

High lysine maize

In 1964 Mertz and coworkers reported the high lysine genes opaque-2 and floury-2. The genes suppressed the synthesis of zein (corn prolamine), which is nutritionally poor, and replaced it mainly with glutelin, which has better amino acid content. Besides the change in protein fraction composition, polypeptide distribution of glutelin was also altered (Lasztity 1996). Positive aspects of opaque-2 gene were higher lysine and tryptophan contents (Bressani 1991) and an improvement of the leucine to isoleucine ratio (Mertz et al. 1964). Lysine in maize is the first limiting amino acid and tryptophan is the second. Even though the protein in the opaque-2 genotypes was more nutritious than normal maize, it was not accepted by farmers. Agricultural use of opaque-2 maize was limited due to lower yield and undesirable kernel characteristics such as soft, chalky and less dense endosperm texture. Kernels dried slower at harvest and had higher incidence of ear rot. This contributed to greater susceptibility to diseases, insect infestation and aflatoxin contamination (Paiva et al. 1991, Yau et al. 1999). Other changes included thicker pericarp, larger germ size, reduced cob weight and reduced color intensity in yellow corns. Effects differ with genetic backgrounds (Vasal 2001).

Quality protein maize

Different approaches have been used to improve the agronomic quality of opaque-2 genotypes. Breeders at the International Maize and Wheat Improvement Center in Mexico have continued working for improvement of protein quality in maize, converting opaque-2 maize into varieties that have high nutritional quality, high yields, appearance of normal maize, greater hardness than opaque-2, equal or superior pest and disease resistance (Paiva et al. 1991, Vasal 2001). This enhanced opaque-2 is called quality protein maize (QPM). QPM also contains nearly twice the lysine and tryptophan, higher amounts of histidine, arginine, aspartic acid, and glycine, and lower amount of glutamic acid, alanine and leucine (Vasal 2001). amino acid content of regular, opaque-2 and quality protein maize grain is shown in Table III. Furthermore, some QPM hybrids contain as much as 13.5% protein (CIMMYT 2001).

Search for better genes has continued and additional mutants are known that improves protein quality of corn endosperm (opaque-7, opaque-6, floury-3, and opaque-11) but no other mutant has been found to offer any additional advantages over opaque-2 gene (Vasal 2001).

Paiva et al. (1991) found changes in the major zein components of QPM. Regular maize had up to seven times more zein than QPM, on the contrary for the "zein-like" fraction, opaque-2, floury-2 and QPM showed twice as much protein than the regular maize. QPM had more γ-zein at the periphery of the protein bodies, compared to opaque-2 and regular maize. γ-zein could be involved in disulfide interactions that influence kernel hardness in QPM genotypes (Paiva et al. 1991, Lasztity 1996). QPMs and opaque-2 showed a stronger reduction of α-zein in going from hard to soft endosperm regions and the γ-zein content was greater in QPM than in regular genotypes regardless of the endosperm region (Paiva et al. 1991).

QPM traits are caused by recessive genes, thus in open pollinated environment, and pollen from normal maize could decrease protein quality. According to CIMMYT (2001), pollen contamination of QPM from other varieties has been significantly less than originally projected. Open-pollinated varieties (OPVs) can be harvested and sown the following season without yield or quality penalty (CIMMYT, 2001).

TABLE III
Amino Acid Content of Regular, Opaque-2 and Quality Protein Maize Grain

Amino acid	Opaque-2 maize [a] (g/ 100 g protein)	QPM[bc] (g/ 100 g protein)	Regular maize [a] (g/ 100 g protein)
Lysine	3.4	4.0	2.0
Histidine	3.4	4.0	2.8
Argininge	5.1	6.3	3.8
Threonine	3.9	3.6	3.5
Serine	5.0	4.3	5.2
Tyrosine	4.7	3.3	5.3
Proline	9.4	10	9.7
Glycine	4.0	4.5	3.2
Alanine	7.0	6.0	8.1
Valine	5.0	5.2	4.7
Methionine	2.0	1.8	2.8
Isoleucine	3.9	3.3	3.8
Leucine	11.6	9.6	14.3
Phenylalanine	4.7	4.9	5.3

[a] Lasztity (1996).
[b] Quality protein maize.
[c] Sproule (1985).

Nutritional impact of QPM

Since the discovery of the opaque-2 gene, various studies on protein quality were conducted in rats, children and adults. Both, metabolic and growth studies in children have been carried out (Graham et al. 1980, Graham et al. 1989, Graham et al. 1990, Bressani 1991). Serna-Saldivar et al. (1992b) studied the bone and plasma composition of rats fed raw grain and tortillas from QPM and regular maize. Femurs of the rats fed with tortillas weighed more, were thicker, longer, denser and stronger (*P*<0.05) than those of rats fed raw grain. Among rats fed tortillas, QPM produced denser, stronger, longer and thicker bones with more ash and Ca. This correlates to the positive effect of L-lysine on Ca intestinal absorption and decrease in urine excretion reported by Civitelli et al. (1992). Sproule (1985) evaluated the nutritional value of QPM and regular maize in weaning rats, comparing raw grain and tortillas from QPM and regular maize. Protein efficiency ratio (PER) of the raw QPM (2.25) was the highest followed by QPM tortilla (1.87), while values for raw food grade maize (1.37) and tortilla (1.37) were significantly lower (*P*<0.05).

The decreased leucine content in QPM compared to regular corn, produce a favorable leucine-isoleucine ratio, which liberates more tryptophan for niacin biosynthesis. For this reason, QPM reduces pellagra significantly, even though QPM has the same niacin content as normal corn (Vasal 2001).

Graham et al. (1980) studied protein quality and digestibility of energy and protein of regular maize and opaque-2 maize whole kernel meals of eight convalescent malnourished children, 10–25 months of age. For both meals there was a strong correlation between lysine absorbed and nitrogen retained. Opaque-2 meal retained 50% more nitrogen compared to regular maize meal.

Worldwide production of QPM

QPM has widespread adoption in developing countries where maize is a staple food. In 1997, 170,000 hectares of QPM were cultivated in Bolivia, Brazil, China, Ghana and South Africa (CIMMYT 2001), which represented 0.12% of the world area harvested for that year (FAOSTAT 2003). According to CIMMYT, in 2001, a total of 750,000 hectares were grown in Brazil, Burkina Faso, China, El Salvador, Ethiopia, Ghana, Guatemala, Honduras, India, Ivory Coast, Mali, Mexico, Mozambique, Nicaragua, South Africa, Togo, Uganda and Vietnam, which represents 0.53% of the world area harvested (FAOSTAT 2003). Farmers in Central Mexico are also growing commercial QPM open pollinated varieties from CIMMYT for animal feed.

Food processing of QPM

Nixtamalization and tortilla processing

The nixtamalization of maize into tortillas and related products has existed for centuries; it was developed by the Mesoamerican Indians (Rooney and Suhendro 1999). The Aztecs cooked maize in alkali to make tortillas. Today, nixtamalization and steeping of corn with 1-5% lime (calcium oxide) is the first step in the manufacture of alkaline corn products such as tortillas, corn chips, tortilla chips, taco shells, and tamales (Katz et al. 1974). The steeped corn or nixtamal is removed from the *nejayote,* washed to remove loose pieces of pericarp and stone ground to produce masa. Masa is shaped into flat circles and baked in further processing. During alkaline cooking, chemical and physical changes occur in the corn kernel, such as starch gelatinization, water uptake and partial removal of the pericarp and germ. During masa production, grinding disrupts the swollen gelatinized starch granule and distributes the hydrated starch and protein around the ungelatinized starch portion (Rooney and Serna-Saldivar 1987). The increased presence of alkaline-cooked corn products emphasizes the importance of maintaining high and consistent product quality standards. To obtain the required degree of cook and proper masa texture is still considered an art and is learned through experience, empirically using subjective methods.

Kernel characteristics, including soundness of the kernel, kernel size, density, and endosperm hardness have been reported to significantly affect the alkaline cooking performance of corn in alkaline cooking (Bedolla and Rooney 1982, Almeida-Dominguez et al. 1998). Furthermore, processing conditions, such as lime concentration, cooking temperature, extent of cooking and steeping, influence the textural characteristics of masa and nixtamalized products (Sahai et al. 1999, Sahai et al. 2001). It is important to control the extent of cooking because it affects pericarp softening and removal, dry matter loss, nixtamal water uptake, starch gelatinization, vitamin availability, and protein quality (Bressani 1990) as well as nixtamal color, texture and flavor. Dry matter losses during alkaline cooking affect the overall solids lost and are responsible for increased plant sewage costs (Almeida-Dominguez et al. 1998). Degree of cooking will also influence further processing parameters such as the gap between the grinding stones and the amount of water added during grinding (Sahai et al. 1999). There is a strong correlation between the degree of cooking and water uptake of the nixtamal, therefore the best way to control this parameter is to monitor the water uptake during the alkaline cooking (Serna-Saldivar et al. 1988).

Serna-Saldivar et al. (1992a) compared QPM of regular maize and noted a significantly shorter cooking time required for QPM because of their smaller kernel size and softer endosperm texture. QPM retained greater amounts of dietary fiber because pericarp was not completely removed during cooking. To increase pericarp removal, longer cooking time would be required and a greater dry matter loss could be expected. Pericarp removal is important in tortilla chip production because it affects color and flavor of the product and accumulates on the wires of the sheeter (Serna-Saldivar et al. 1991). Conversely, Sproule (1985) reported a longer cooking time required for QPM in the production of tortillas compared to regular maize, due to a higher amount of corneous endosperm. Dry matter losses were significantly ($P < 0.05$) lower in QPM than regular maize. This is consistent with the pericarp adhering more firmly to the endosperm (Serna-Saldivar et al. 1992a). Sproule (1985) reported QPM tortillas were less accepted due to a more rubbery texture compared to regular tortillas. The test was conducted with limited quantities of product and further experimentation was suggested.

Compositional changes during tortilla processing of QPM have been previously reported (De Groot and Slump 1969, Sproule et al. 1988, Ortega et al. 1986, Bressani 1990). Ortega et al. (1986) reported a decrease in tryptophan content of 11% in tortilla made from regular maize and 15% in tortillas made of QPM. QPM tortillas however, had 72% more tryptophan than regular maize tortillas. Available lysine was

73% higher in QPM tortillas compared to regular maize tortillas while the loss of lysine content was minimal during processing of regular maize and QPM tortillas.

Extrusion processing

Extrusion cooking technology has been widely used in the food industry (Ali et al. 1996). It is a continuous process that uses both temperature and pressure for cooking and expansion (Mathew 1999a). Two types of extruders are commonly used, twin-screw extruder and single-screw extruder (Riaz 1997). Many extruders in the snack industry are single-screw, short-barrel extruders with a length-over-diameter (L/D) of 4 or less. In this type of extruders all the heat is developed by friction (Burtea 2000).

Corn meal is a major ingredient for extruded foods, such as ready-to-eat breakfast cereals and snacks (Gujral et al. 2001) Corn meal is obtained from a dry milling process. In dry milling, the physical characteristics of the individual kernels are extremely important. Maize with low test weight often has a lower percentage of hard endosperm; therefore it produces a lower yield of prime, large grits when milled (Dorsey-Redding et al. 1991).

During extrusion corn is heated sufficiently inside the extruder to gelatinize the starch and disrupt the protein matrix. The viscoelastic material is forced through a die and the sudden pressure drop causes part of the water to vaporize giving an expanded and porous structure (Ilo et al. 1996).

Expansion volume is the primary quality parameter associated with product crispiness, water absorption, water solubility and crunchiness (Ali et al. 1996). Expansion depends upon feed composition, amount of cooking and melt flow in the die (Desrumaux et al. 1998). It has also been reported to be the most dependent on material moisture content and extrusion temperature (Ilo et al. 1996). De Muelenaere and Buzzared (1969) extruded whole corn meal and degermed corn meal and reported that degermed corn grit had greater expansion.

Wichser (1966) evaluated dry milling characteristics of opaque-2 maize. Opaque-2 maize compared to regular corn had larger germ making up a greater percentage of the kernel, it also had a slight amount of horny endosperm and lower thousand kernel weight. The pericarp was tougher and strongly adhered to the endosperm. Germ separation was harder because the endosperm remained attached to the germ. The grinding process was affected by the opaque-2 maize because of the lack of horny endosperm. The floury endosperm produced longer, flatter and whiter flaking grits than regular corn. Opaque-2 maize produced 8.8 % flaking grits from the total corn milled compared to 17.2% from regular corn. Twenty six years later, Wu (1992) reported QPM can be degermed and roller milled with yields of total grits and prime products comparable to those from conventional dent corn. Lysine and tryptophan values of the grits and prime products were not evaluated during this experiment. Studies on processing QPM by extrusion have not yet been reported.

CHAPTER III
MATERIALS AND METHODS

Sources of grain

Grains used include quality protein maize (QPM), high protein corn (HPC) and food grade maize (FGM) (Table IV).

TABLE IV
Description of the Maize Samples

Sample name	Origin	Description	Process
Y-FGM	Illinois	Commercial yellow food grade maize hybrid	Nixtamalization
W-FGM 1	Illinois	Commercial white food grade maize hybrid	Nixtamalization
W-FGM 2	Texas	Commercial white food grade maize hybrid	Extrusion
Y-QPM 1	College Station, TX	Yellow quality protein maize hybrid. Single cross TxXQ69-B3/TX804.	Nixtamalization
Y-QPM 2	College Station, TX	Yellow quality protein maize hybrid Single cross TxXQ69-B4/TX804.	Nixtamalization
Y-QPM 3	College Station, TX	Yellow quality protein maize hybrid. Mixture of three-way crosses between hybrids of CMLs 161,193, 172 with inbred Tx804.	Nixtamalization
W-QPM 1	College Station, TX	White quality protein maize hybrid. Mixture of single crosses CML176 x Bo46w and CML176 x Bo59w	Nixtamalization
W-QPM 2	College Station, TX	White quality protein maize. Mixture of single crosses CML184 x Bo59w, CML184 x Tx811 and CML184 x CML176.	Nixtamalization
W-QPM 3	CIMMYT[a]	White quality protein maize. Open pollinated variety S99TLWQ.	Nixtamalization and extrusion
W-HPC	Ohio	White high protein corn hybrid. 1851W.	Nixtamalization and extrusion

[a] International Maize and Wheat Improvement Center in Mexico

Three yellow QPM and two white QPM samples were grown in the Texas Agricultural Experimental Station at College Station in 2002. A commercial hybrid of HPC, from Wilson Genetics was grown in Ohio 2002 under high yield conditions. One open pollinated variety of white QPM was grown in CIMMYT (International Center of Maize and Wheat Improvement) at Mexico in 2001. Two commercial FGM with outstanding alkaline-cooking properties were grown in Illinois. QPM grown in Texas was available in limited quantities. Samples were cleaned and stored at –10°C prior to use.

Physical tests

Test weight

Test weight (lb/bu, kg/hL) was determined according to the Official U.S. Grain Standard Procedure (USDA 1974). One pint cup was tared and filled with grain using the Winchester Bushel Meter. The grains fell freely into the cup, the cup was leveled with a strike-off stick with zig-zag motions, the cup content weighed and expressed as pounds per bushel. Analyses were done in triplicate for each corn variety.

1000 Kernel Weight (TKW)

TKW was determined by weighing 40 sound kernels randomly selected from each sample. The weight was then multiplied by 25. Analyses were done in triplicate for each corn variety.

Density

Density (g/mL) was determined by gas displacement with a nitrogen comparison quantachrome multipycnometer (model MVP-1, Quatachrome Corporation, Syosset, NY) using a 80 g sample with a large cell. Analyses were done in duplicate for each corn variety.

Grain hardness

An estimation of the kernel hardness was obtained from the percent weight removed by abrasive milling of kernels using the tangential abrasive dehulling device (TADD) (Model 4E-115, Venables Machine Works, Saskatoon, SK, Canada). An aluminum oxide abrasive disk (38A36-LSVBE) and 8-hole base was used. Samples (40 g) were decorticated for 8 min and the difference in weight was measured as % matter removed. Analyses were done in triplicate for each corn variety.

Color

Color (L*, a*, b*) was determined for grain, masa, tortilla and extrudates with a Minolta Chrome Meter portable colorimeter (Model CR 310, Minolta Co., Ramsey, NJ). The standard tile was L*=+93.48, a*=-0.89 and +b*=-0.86. Values determined were L* as lightness (100) to darkness (0); a* as redness (+a*) through greenness (-a*) and b* as yellowness (+b*) through blueness (-b*). Ten replicates per corn variety were analyzed for grain samples. In the case of masa, tortilla and extrudates, four replicates per treatment were analyzed. Extrudates were ground and passed through a No. 30 US standard sieve. prior to color measurement.

Chemical analysis of raw and processed samples

Moisture

Moisture content was determined gravimetrically by the AACC method 44-15A using a hot air oven (Model 16, Precision Scientific Co. PS, Chicago, IL). Samples (2 g) were dried at 103°C for 72 hr, removed and placed in a desiccator for 1 hr and final weight was recorded. Moisture content was calculated using the Equation No. 1.

$$\textbf{(1)} \quad \textbf{\% Moisture} = \frac{\text{Initial weight (g)} - \text{Final weight (g) X}}{\text{Initial weight (g) x 100}} \text{100}$$

pH

Hydrogen-Ion activity (pH) was determined following the electrometric method (AACC 02-52) for masa and tortilla. Samples were analyzed in triplicate.

Fiber, fat and protein content

Crude fiber, crude fat and crude protein content were analyzed using a near infrared spectrophotometer (model 6500, NIRSystem, Perstorp Analytical, MD). Prior to analysis, samples were ground with a UDY Cyclone mill (model 3010-030, Udy Corporation, Fort Collins, CO, 80524) with 1mm opening mesh. Samples were analyzed in triplicate.

Amino acid analysis

Grain samples and corn meal were analyzed for protein and amino acid content. Analyses were performed by the University of Missouri Experimental Station chemical Laboratories. Crude protein was determined by combustion method (AACC 46-30). The conversion factor used was Crude protein = % N X 6.25. Lysine and tryptophan analysis were performed according to the official method (AOAC 982.30 E (a, b, c) 1995). Results were expressed as grams per 100 grams of protein.

Preliminary alkaline cooking properties

Pericarp removal

Pericarp removal was evaluated subjectively following the procedure described by Serna-Saldivar et al. (1991). Samples made of 20 to 30 kernels were cooked in 45 L of water and 150 g of lime for 20 min and rinsed gently without removing the remaining pericarp. Kernels were submerged 15 sec in a May-Gruenwald dye. The remaining excess dye was removed by rinsing the kernels sequentially in 3 beakers containing methanol. The May-Gruenwald solution contained 1 g of eosine Y, 1 g of methylene blue and 200 mL of methanol. The solution was diluted with three volumes of methanol prior to use. Kernels were subjectively evaluated using a scale form 1= all pericarp was removed to 5= none of the pericarp was removed. A picture of the standards used is shown in Appendix A.

Optimum cooking time determination

Optimum cooking time was obtained following the methodology described by Serna-Saldivar et al. (1993). Corn samples (100 ±0.1 g) were placed in perforated nylon bags and boiled in a lime solution (45 L of water and 150 g of lime) for 0, 15, 30 and 45 min and steeped for 12 hr. The water was kept at 97-98°C in a 120 L steam kettle (model TDC/2-20, Groen Div., Dover Corp., Elk Grove Village, IL.). During steeping, the temperature was reduced at a rate of 0.10°C/min. Nixtamal was washed for 30 sec, drained, dried at room temperature for 10 min and weighed. The nixtamal was returned to the bag, dried in a convention oven at 100°C for 48 hr, cooled in a desiccator and weighed. Moisture content, water uptake and dry matter losses were calculated according to formulas 1 and 2. Cooking time was obtained by linear regression to reach 50% moisture.

$$\textbf{(2)}\quad \textbf{Nixtamal Moisture (\%)} = \left(\frac{\text{Wet nixtamal weight} - \text{Dry nixtamal weight}}{\text{Wet nixtamal weight}}\right) * 100$$

$$\textbf{(3)}\quad \textbf{Dry Matter Losses (\%)} = \left(\frac{\text{Dry grain weight} - \text{Dry nixtamal weight}}{\text{Dry nixtamal weight}}\right) * 100$$

Tortilla processing

Samples (2.5 Kg) were processed into tortillas in the Texas A&M Pilot Plant. Each batch was composed of 15 Kg. Samples were placed in perforated nylon bags. Each corn variety was optimum cooked, according to the information collected from the cooking trials. Water temperature was kept at 97-98°C in a 120 L steam kettle. The boiling solution contained 45 L of tap water and 150 g of lime. After cooking the corn, the steam was cut off, and the corn was steeped for 12 hr. The nixtamal was hand washed with running tap water to remove the excess of lime and pericarp. Cleaned nixtamal was ground in a stone-ground with 12 in diameter lava stones, using a 20-hp commercial grinder (model CG, Casa Herrera Inc., Los Angeles, CA.).

A solution of 300 ml of water with 0.5% of fumaric acid and 0.5 % of potassium sorbate (based on the dry kernel weight) was added to the nixtamal during grinding. To disperse the additives, the masa was mixed during 4 min in low speed using a Hobart mixer (model A-200, Hobart Co., Troy, OH).

The masa was sheeted and formed continuously into 30 g ± 1 g tortilla discs in commercial sheeter/former (Model CH4-STM, Superior Food Machinery, Inc., Pico Rivera). Tortillas were continuously baked for 60 sec in a gas-fired oven with a three-tier moving belt (model C0440, Superior food Machinery, Inc. Pico Rivera, CA). The average temperatures were 320, 270 and 250°C for the top, middle, and bottom tiers. Once baked, the tortillas were conveyed into a three-stage cooling rack (model 3106-INF, Superior Food Machinery, Inc. Pico Rivera, CA) for 2 min and equilibrated at room temperature for 5 min on a table, and were turned over to equilibrate for an additional 5 min. Tortillas were weighed and stored in low-density polyethylene bags at 25°C for up to 120 hr.

Nixtamal analysis

Nixtamal was analyzed for moisture uptake (Equation 2), dry mater losses (Equation 3) and nixtamal shear force.

Nixtamal *shear cell force*

Samples (30 g) of nixtamal optimum cooked were evaluated using a texture analyzer (model TA.HDi Texture Technologies Corp, Scarsdale, NY/Stable micro Systems, Godalming, Surrey, UK) (Figures 1 and 2). The aluminum cell device consisted of a barrel (152.4 mm height, 25.3 mm internal diameter), a plunger (25 mm diameter), and a die (12.5 mm diameter opening). Nixtamal samples (30 g) were placed inside the barrel and extruded completely with the plunger. The plunger traveled a distance of 120 mm at a test speed of 1.5 mm/sec with a trigger force of 0.196 N. Total work (Nm) and peak force (N) were measured in triplicate (Bedolla 1980). A typical curve is shown in figure 3.

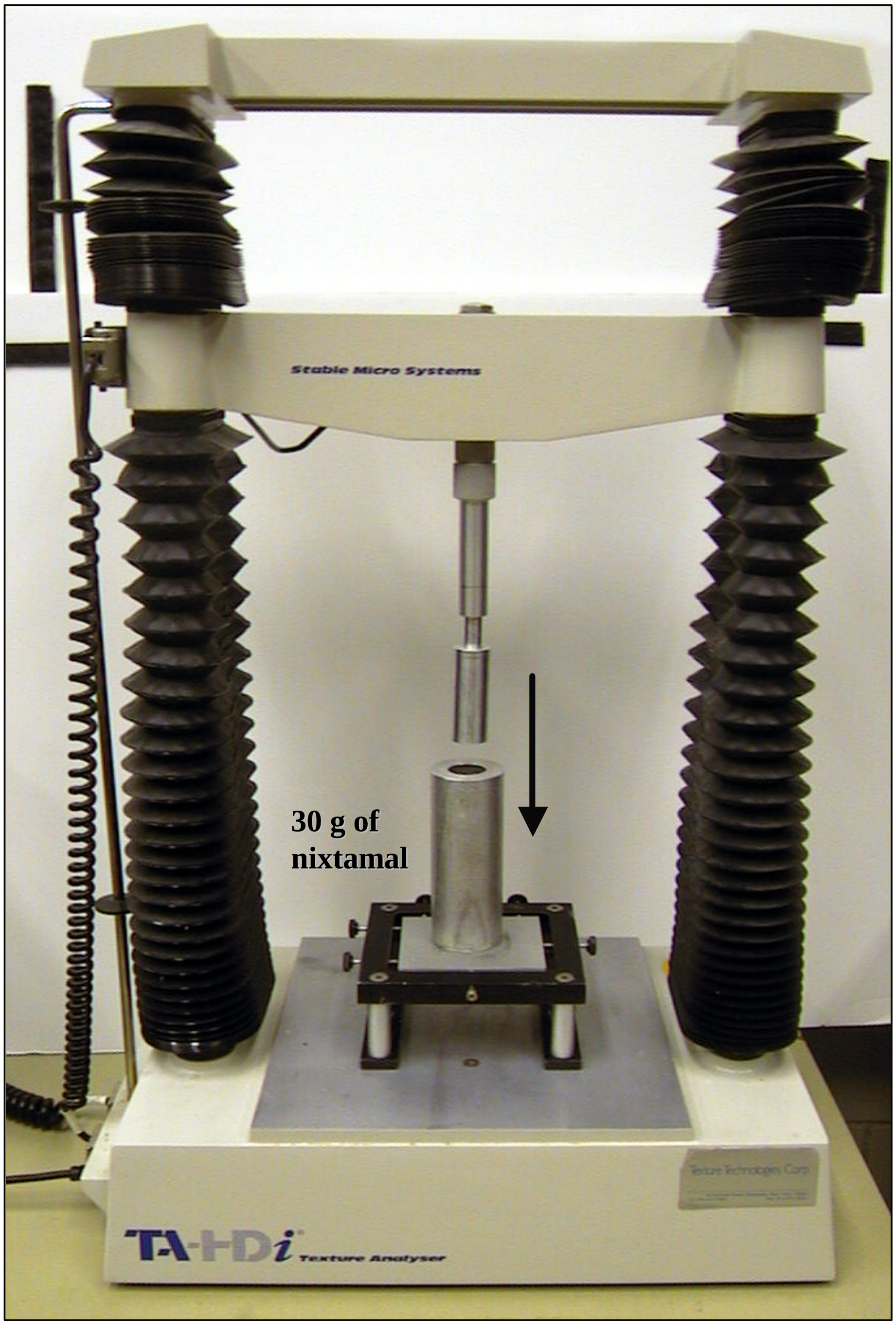

Fig. 1. Texture analyzer TA. HD*i* used to analyze nixtamal shear force.

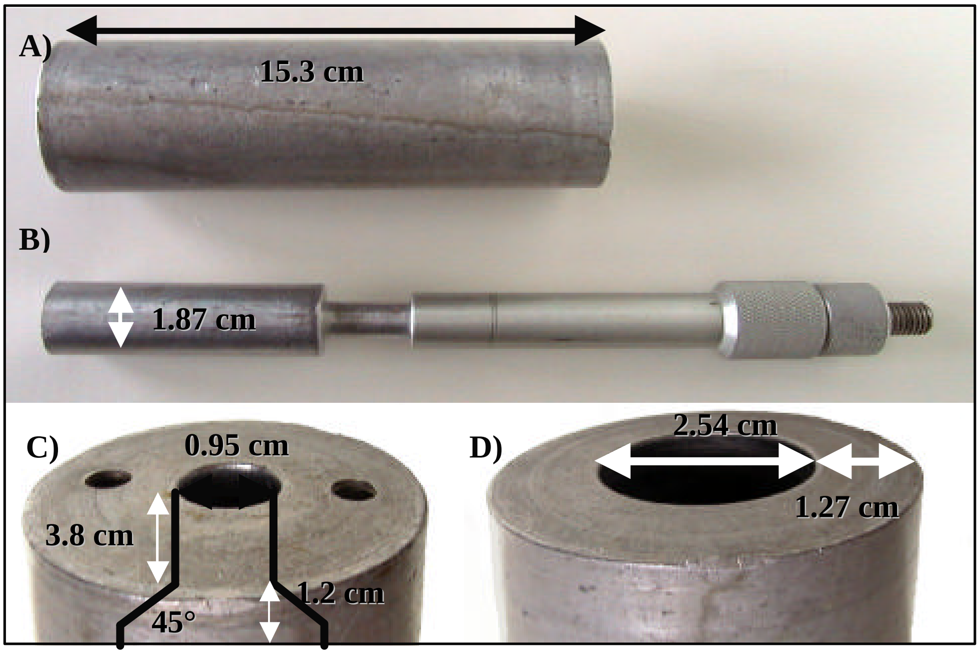

Fig. 2. Cone and die shear cell used to measure nixtamal shear force. A) Cone; B) Plunger; C) Cone exit (die); D) Cone entrance.

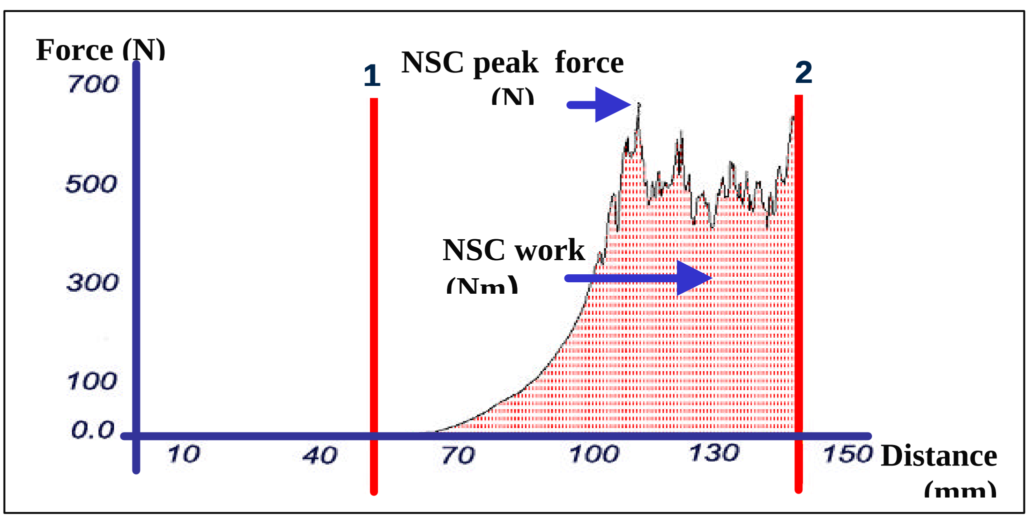

Fig. 3. Typical TA.HDi Texture analyzer force curve for nixtamal forced though a cone and die shear cell.

Masa analysis

Masa was analyzed for particle size distribution, masa rheology, moisture, pH and color. Masa rheology, moisture and pH were analyzed immediately after grinding and the rest of the analysis were done the day after.

Particle size distribution

A method adapted from Gomez (1988) and Pflugfelder et al. (1988b) was used to evaluate the particle size distribution. Samples of masa (10 g) were submerged in 50 mL of distilled water an let sit over night. Samples were sifted with 150 mL of distilled water using No. 20 (850 µm) US Standard sieves, No. 60 (250 µm) and No. 100 (150µm). The liquid that passed sieve No. 100 was collected and centrifuged at 2800 G X 8 min. The centrifuged precipitate was collected and placed in a tared capsule. Fractions retained on each sieve were removed using tap water, placed in tared capsules and dried in a forced air oven at 100°C for 24 hr weighed and expressed as percentage. Analyses were done in duplicate per sample.

Rheology of the masa

Masa dough properties were subjectively evaluated for stickiness, hardness and machinability using a rating scale from 1=low to 5=high (Yeggy 2000).

Tortilla analysis

Baked tortillas were analyzed for color. During storage time (0.5, 24, 72, and 120 hr) extensibility, rollability and pliability were also measured using the methods described as follows.

Objective 1-D extensibility

Extensibility was conducted using a texture analyzer (model TA.XT2*i*, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) (Suhendro et al. 1999) (Fig. 4). A tortilla strip (70 X 35 mm) was cut between baking lines with an acrylic template. The tortilla strip was placed between two clamps

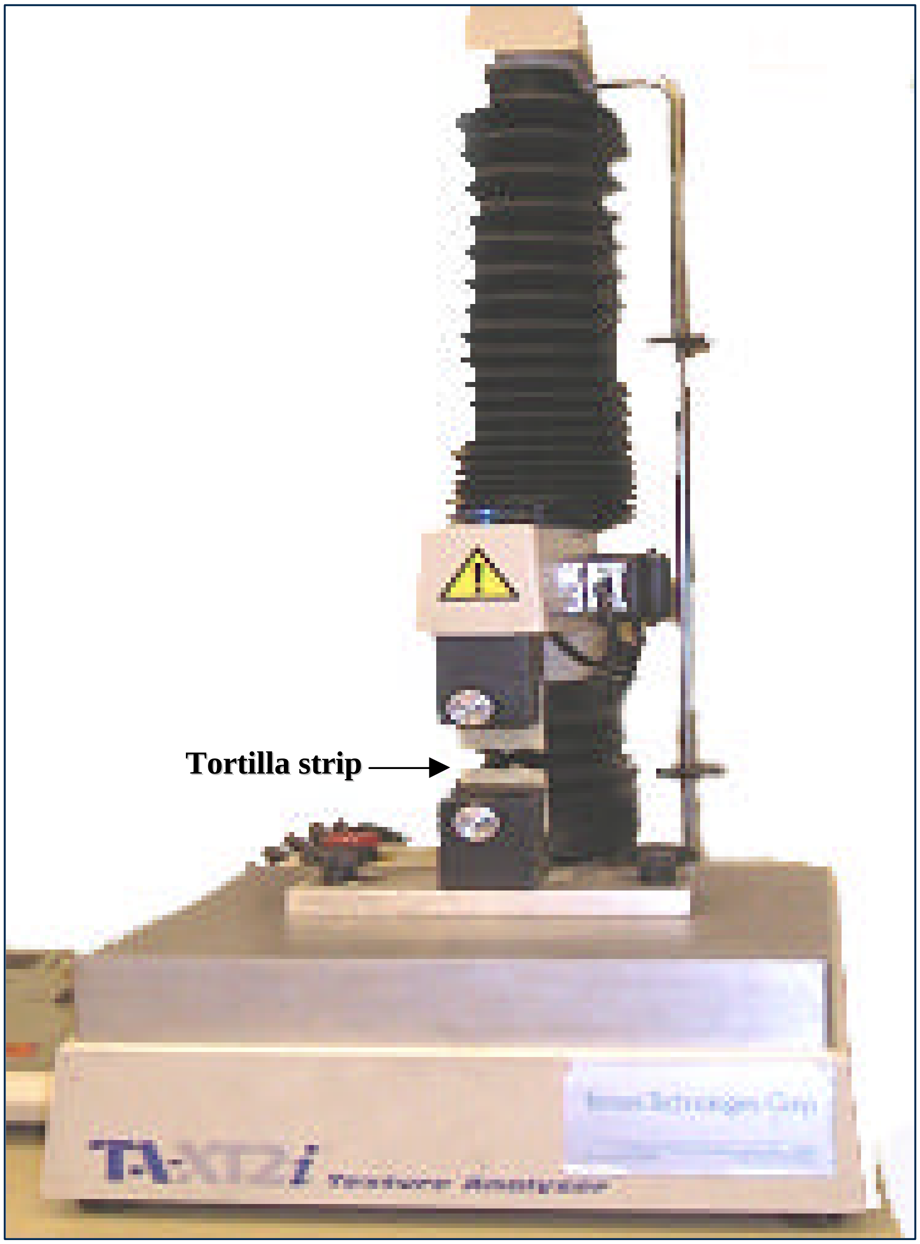

Fig. 4. Texture analyzer (TA.X T2*i)* used to analyze tortilla extensibility during storage time.

vertically aligned. One clamp was attached to the moving arm and the other was attached

Subjective rollability

Rollability was evaluated at different storage times (0.5, 24, 72, and 120 hr) by wrapping and rolling a tortilla around a 1 cm diameter dowel. Rollability was subjectively recorded using a scale of 1– 5 (1=least flexible, 2=hard to roll 3=cracks are more noticeable, 4=a few small cracks 5=returns to original shape) (Suhendro et al. 1998).

Subjective pliability

Pliability was subjectively evaluated at different storage times (0.5, 24, 72, and 120 hr) to measure overall flexibility. One tortilla was squeezed in the hand and evaluated by a trained person. The overall firmness score was rated from 1 to 5 (1=broken, 2=less than 3 cracks, and some part broken 3=cracks more but retain shape 4=few small cracks 5=returns to original shape) (Fernandez et al. 1999).

Corn meal production

A flow chart of the short scale dry milling system is shown in Figure 5. Samples were decorticated 10% by an abrasive dehuller (PRL Mini-Dehuller, Nutana Machine Co. Saskatoon, Canada) to remove part of the germ and pericarp and cleaned with a KICE grain cleaner (Model 6DT4-1, KICE Industries Inc., Wichita, KS). Decorticated samples were sifted with a No. 5 (4 mm) US standard sieve to eliminate germ chunks that were not removed by the cyclone. Particles that passed through the sieve were discarded. Decorticated samples and non-decorticated samples were milled in a Jay Bee hammer mill (model 1047, Manufacturing Inc., Tayler TX) at 3600 RPM, through a 2 mm opening mesh. To achieve different particle size, samples were sifted through a No. 20 (850 µm) US standard sieve and No. 40 (425 µm) sieve. Samples over No. 20 (850 µm) sieve were called coarse, through No. 20 (850 µm) and over No. 40 (425 µm) were called medium, and samples that passed through sieve No. 40 (425 µm) were called fine and were discarded.

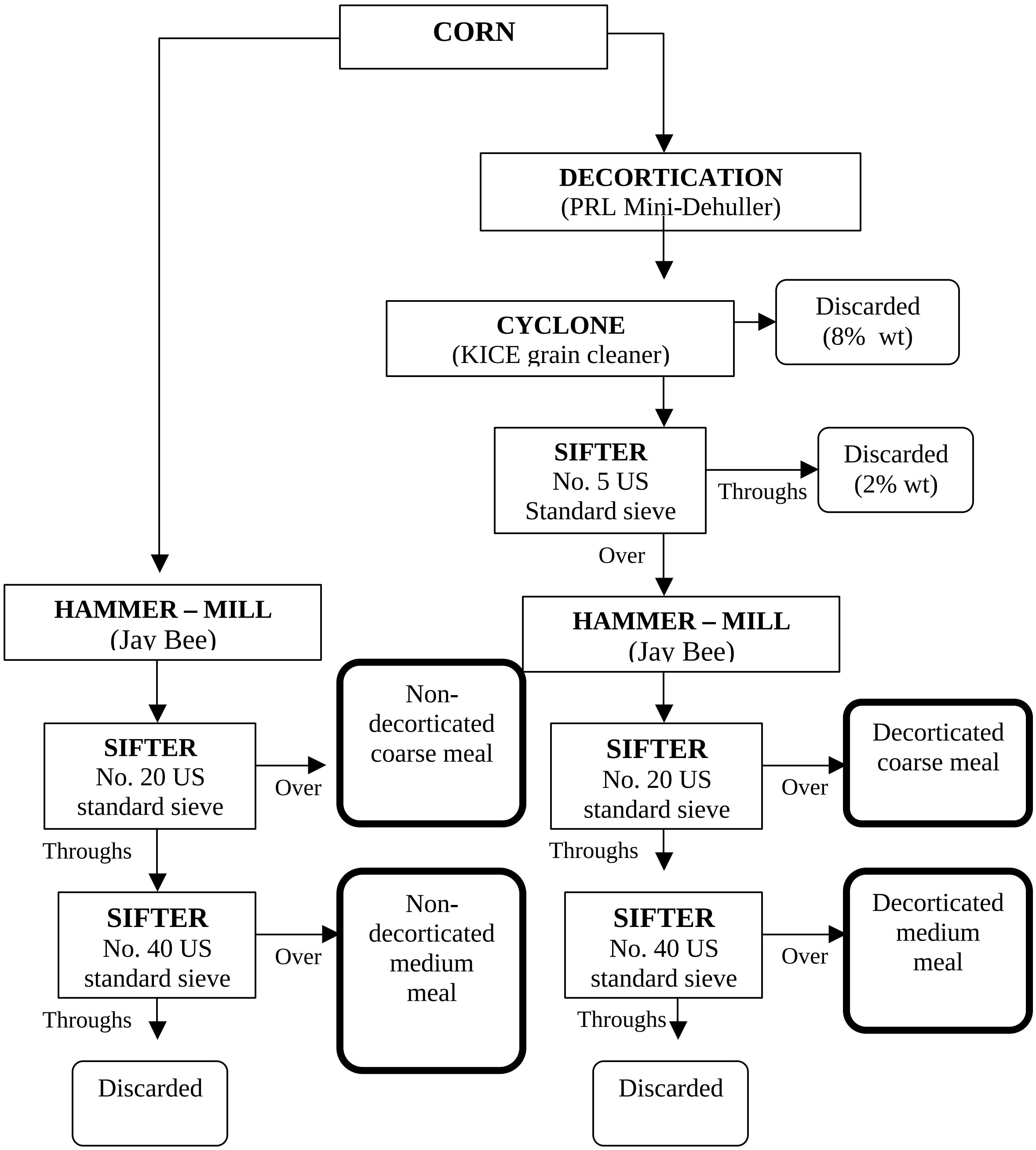

Fig. 5. Flow chart of corn meal production using a short scale milling system. The final products (treatments) and the mean yields are shown in the squares with thicker line.

Direct-expanded extrusion process

Samples were extruded in a single-screw, short barrel, high friction, high shear, Maddox extruder (Model MX 300I, Dallas, TX). Extrusion was performed, without heat added, holding a constant knife speed at 25 and 330 RPM for all samples. Sample feed rate, amperage and temperatures (°C) were monitored during processing. Specific mechanical energy (SME) was calculated by the equation 4:

$$\textbf{(4)}\quad \textbf{SME} = \frac{\text{(Torque) (Screw speed)}}{\text{Feed rate}} \qquad \text{(Grooper 2002)}$$

Torque was obtained from the amperes using a table generated by Emerson/US Motors for an electric motor of 420 volts (Appendix A). Extrudates were baked at 115°C for 15 min in a forced air electric oven (model V-21, Despatch Oven Co., Minneapolis, MN), equilibrated for 5 min, vacuum packed in metalized bags, and stored at room temperature.

Extrudate analysis

Baked extrudates were analyzed for bulk density, apparent volume, radial expansion, color and break force using the methods described as follows.

Bulk density

Bulk density (g/mL) was calculated taring a container of known volume and filling it with sample. Sample weight was divided by the volume. Analyses were performed in triplicate.

Radial expansion ratio and apparent volume

Radial expansion ratio was calculated by dividing the extrudate average diameter (mm) by the die diameter. The extrudate diameter and length were the mean of 10 random measurements made with a vernier caliper (Chicago Brand, NTX, Inc., Cleveland, OH). Apparent volume was obtained following equation 5:

$$\textbf{(5) Apparent volume} = \pi \left(\frac{\text{Extrudate diameter (mm)}}{2}\right)^2 \text{ (Extrudate length (mm))}$$

Extrudate breaking force

Breaking force of the extrudate was evaluated using a texture analyzer TA.XT2*i* (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) using a flat platform to break the extrudates with a plastic blade probe (54.83 mm long with a 45° angle). The test speed was 1 mm/sec and the rupture test distance 1 mm. Samples were baked and vacuum packed prior to analysis. The break force peak (g) required to break the extrudate and the number of force peaks were recorded. Twenty measurements per treatment were recorded (Mathew et al. 1999b).

Organoleptic determination

Thirty untrained panelists from Texas A&M University evaluated the corn extrudates. The extrudates evaluated were made from the coarse particle size meal from QPM, FGM and HPM since this treatments had the best properties. Samples were flavored and baked before the sensory test to guaranty low moisture content. Flavored extrudates were evaluated for crispiness and adhesiveness using an intensity scale (1=very easy to 9=very hard). The acceptability of the shape, hardness and flavor was evaluated using a hedonic scale (1=extremely dislike to 9=extremely like) (Camire et al. 1991, Pedrero and Pangborn 1997). A sample form used by the panelists during the evaluation is shown in Appendix A.

Statistical analysis

The number of replicates varied according to the analysis. Treatments were completely randomized. Data was analyzed with the SAS System for Windows Version 8e (SAS Institute Inc., Cary, NC, USA, 1999-2000). Least significant differences (LSD) and analysis of variance (ANOVA) tests were conducted with a confidence level of 95% by the general linear model (GLM).

CHAPTER IV

KERNEL PROPERTIES OF FOOD GRADE MAIZE, QUALITY PROTEIN MAIZE AND HIGH PROTEIN CORN: RESULTS AND DISCUSION

The objective of this experiment was to evaluate the physical and chemical properties of six quality protein maize (QPM), three food grade maize (FGM) and one high protein corn (HPC). Samples origin and description are shown in Table V. Physical analyses included test weight (TW), thousand kernel weight (TKW), density by gas displacement, hardness with the tangential abrasive dehulling device, and color (L*, a* and b*).

TABLE V
Description of Raw Materials

Sample name	Origin	Description	Process
Y-FGM	Illinois	Yellow food grade maize	Nixtamalization
W-FGM 1	Illinois	White food grade maize	Nixtamalization
W-FGM 2	Texas	White food grade maize	Extrusion
Y-QPM 1	College Station, TX	Yellow quality protein maize	Nixtamalization
Y-QPM 2	College Station, TX	Yellow quality protein maize	Nixtamalization
Y-QPM 3	College Station, TX	Yellow quality protein maize	Nixtamalization
W-QPM 1	College Station, TX	White quality protein maize	Nixtamalization
W-QPM 2	College Station, TX	White quality protein maize	Nixtamalization
W-QPM 3	CIMMYT[a]	White quality protein maize	Nixtamalization and extrusion
W-HPC	Ohio	White high protein corn[b]	Nixtamalization and extrusion

[a] International Maize and Wheat Improvement Center in Mexico
[b] This high protein corn hybrid usually produces 2% points higher protein than the usual dent corn hybrids. I was produced under high yields so its protein content is lower than the corn hybrids in this trial.

TABLE VI
Physical Properties of Food Grade Maize, Quality Protein Maize and High Protein Corn[a]

Sample[c]	TKW[d]	Density	Hardness	Test weight	
	(g)	(g/mL)	(% removal)	(lb/bu)	(kg/hL)
FGM $\bar{X}$	329.7 b	1.327 a	44.3 b	61.4 a	79.0 a
QPM $\bar{X}$	322.3 b	1.313 a	48.7 a	60.7 a	78.1 a
HPC $\bar{X}$	367.5 a	1.313 a	48.1 a	61.2 a	78.7 a
LSD[b] $\bar{X}$	**9.8**	**0.02**	**4.1**	**1.01**	**1.30**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Variety average. FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn. Results of all samples are shown in appendix B.
[d] Thousand kernel weight.

Chemical analysis included crude protein, crude fiber, and crude fat using a near infrared spectrophotometer; moisture content and amino acid analysis.

Kernel physical characteristics

Thousand kernel weight (TKW), density (g/mL), hardness expressed as percentage of removal and test weight (TW) (lb/bu, Kg/hL) are shown in Table VI and appendix B. TKW values were between 310 and 367 g for all samples (Fig. 6). HPC had the greatest TKW and largest kernel size, followed by FGM and QPM. QPM had similar kernel size than FGM. QPM kernels in this experiment had greater TKW compared to 295.3 g reported by Sproule et al. (1988), and 284 g for yellow QPM and 288 g for white QPM reported by Serna-Saldivar et al. (1992a). It can be implied that the QPM kernel size has been increased. TKW greater than 300 g are recommended for nixtamalization (Rooney and Bockholt 1987). Therefore all samples had acceptable kernel size for nixtamalization.

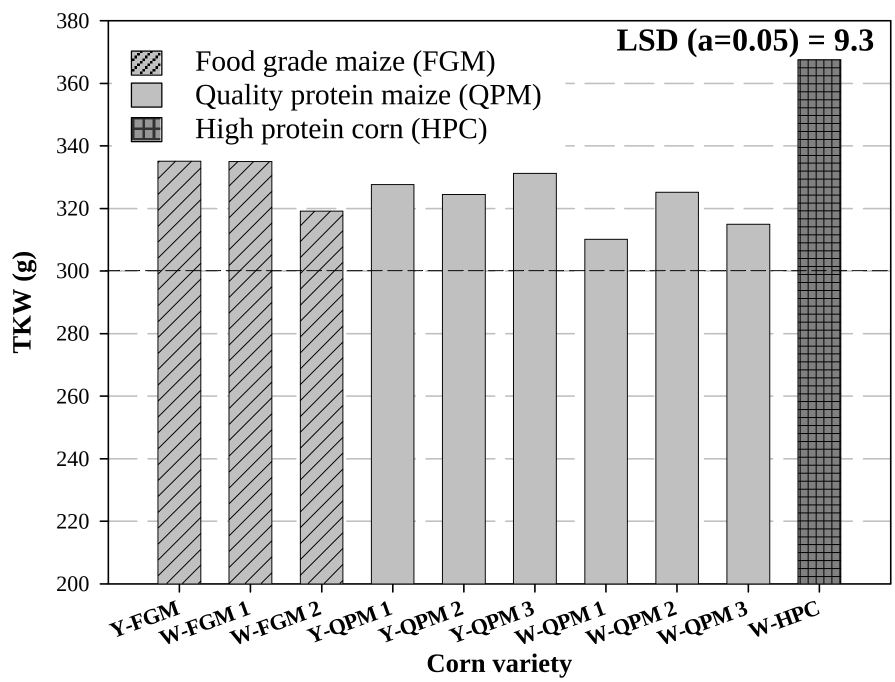

Fig. 6. Thousand kernel weight (TKW) of three food grade maize (FGM), six quality protein maize (QPM) and one high protein corn (HPC). Y = yellow and W = white. LSD = Least significant difference for means separation at 0.05 level. Dotted line = Value recommended for alkaline cooking and dry milling (Rooney and Bockholt 1987).

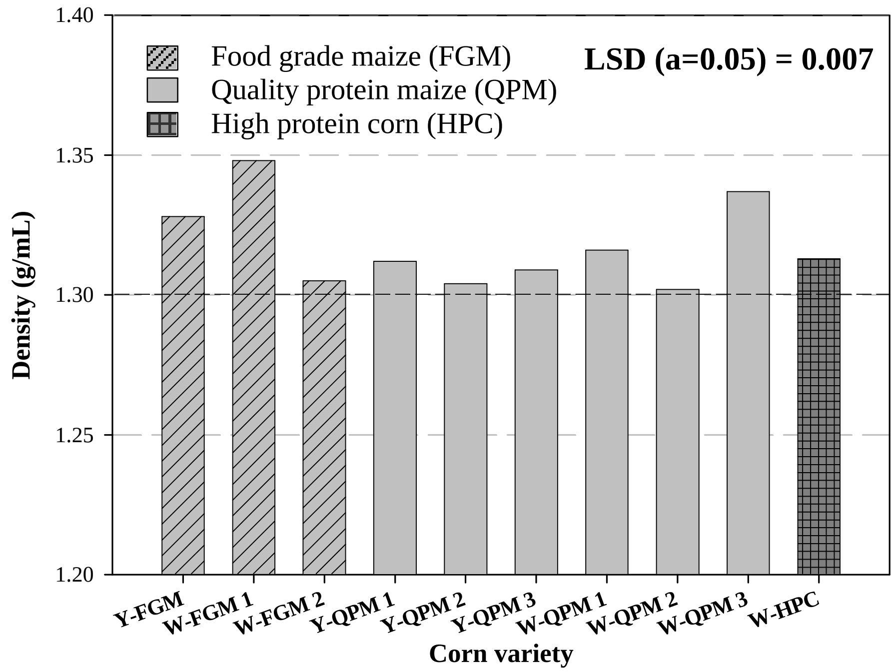

Fig. 7. True density (g/mL) of three food grade maize (FGM), six quality protein maize (QPM) and one high protein corn (HPC). Y = yellow and W = white. LSD = Least significant difference for means separation at 0.05 level. Dotted line = Value recommended for alkaline cooking and dry milling (Rooney and Suhendro 2001).

Kernel densities were between 1.303 and 1.348 g/mL (Fig. 7). In average, all corn varieties had similar ($P < 0.05$) densities (Table VI). Among QPMs, W-QPM 3 from CIMMYT had the greatest ($P < 0.05$) density. In this experiment, QPM samples were less dense than 1.40 g/mL previously reported by Sproule et al. (1988). Values above 1.3 g/mL are recommended for alkaline processing (Rooney and Bockholt 1987). Therefore all samples had adequate density for alkaline cooking and dry milling.

Grain hardness, based on the amount of material abraded was between 41.4% and 52.0% removal (Fig. 8). In average, HPC and QPM were softer than FGM (Table VI). W-QPM 3 was the hardest QPM. Grain hardness was positively related to grain density (R^2=0.90). Denser corns have higher hardness values because the endosperm is more tightly organized without empty spaces (Hosney 1994). The development of harder endosperm in QPM is associated with a two to threefold increase in the γ-zein storage protein compared to opaque-2 (Gloverson et al. 1995). Hard dent corn is desired for alkaline cooking and dry milling. However kernels too hard (flint) may not be acceptable because they take too long to cook during alkaline cooking and their meal requires additional time to hydrate in the preconditioner when extruding (Rooney and Suhendro 2001).

Test weight (TW) ranged between 76.1 and 80.4 kg/hL (59.2 and 62.5 lb/bu) (Fig. 9). Yellow QPMs had greater TW than yellow FGM. TW is affected by kernel size, density, hardness, moisture content and other factors (Rooney and Suhendro 2001). Grain with TW values above 60 lb/bu (77.2 kg/hL) performs well during alkaline cooking (Rooney and Bockholt 1987). In general, higher TW is related to harder kernel. Maize with low TW often has a lower percentage of hard endosperm and produces lower yield of large, prime grits when milled (Rutledge 1978). For dry milling, test weight is used to pay premiums to farmers who produce low stressed-cracked corn of a certain hybrid (Rooney and Suhendro 1999). TW within a given hybrid provide more information than comparisons across hybrids (Rooney and Suhendro 2001).

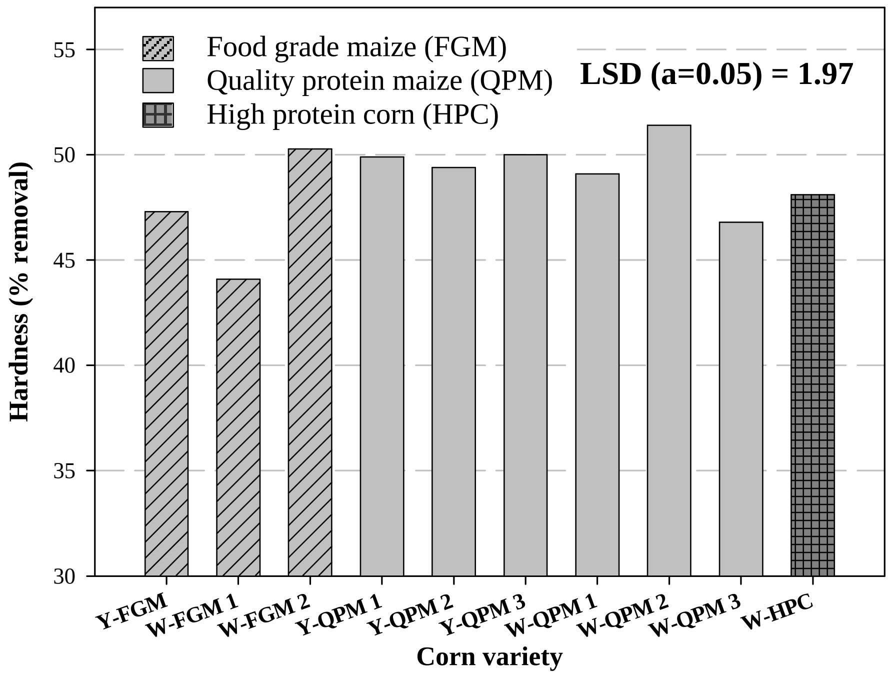

Fig. 8. Hardness expressed as percentage of grain removed of three food grade maize (FGM), six quality protein maize (QPM) and one high protein corn (HPC). Y = yellow and W = white. LSD = Least significant difference for means separation at 0.05 level.

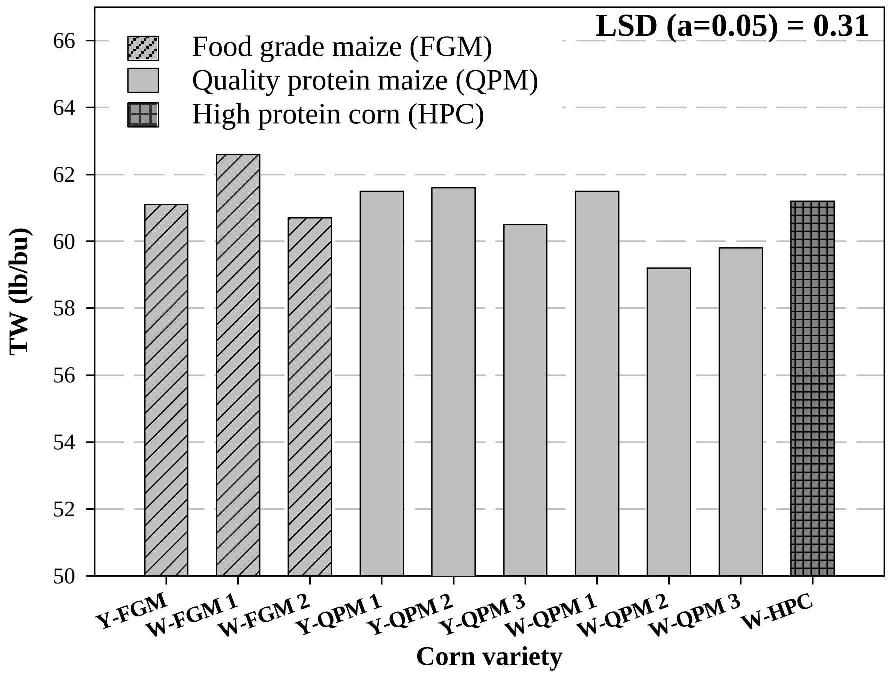

Fig. 9. Test weight (lb/bu) of three food grade maize (FGM), six quality protein maize (QPM) and one high protein corn (HPC). Y = yellow and W = white. LSD = Least significant difference for means separation at 0.05 level. Dotted line = Value recommended for alkaline cooking and dry milling (Rooney and Bockholt 1987).

Kernel color is shown in Table VII and Table VIII. Yellow QPMs had similar b* (yellowness) values and greater L* values (lighter) compared to yellow FGM (*P* < 0.05). Vasal (2001) reported opaque-2 to be less yellow than FGM. Y-QPM had similar b* value to FGM therefore yellow QPM has improved yellowness. Among white maize varieties, W-FGM was darker and less yellow than W-QPM and W-HPC. W-FGM 2 was the lightest (*P* < 0.05) and W-QPM 3 was the darkest. Maize with a clean, bright white or yellow color is preferred by alkaline processors (Rooney and Suhendro 1999). Pigments responsible for color are in the pericarp, aleurone layer, endosperm and scutellum and are affected by pericarp thickness and cob color (Floyd et al. 1995).

Floyd et al. (1995) compared a subjective evaluation method to the objective method using L* a* and b* values. Yellow corn type subjectively evaluated as bright, clean yellow had L*, a* and b* values of 57.7, 12.0, and 28.3, respectively. The four yellow corns evaluated in this experiment were lighter and more yellow. White corn subjectively evaluated as bright and clean white had values of L*=66.4, a*=1.1 and b*=22.3 (Floyd et al. 1995). All white varieties analyzed were lighter and W-QPM-3 and W-HPM were more similar to the L* value compared to FGM. W-QPM 1 and W-QPM 2 were more yellow.

QPM kernel properties from this experiment are different from opaque-2 reported by Wichser (1966). Opaque-2 had lower test weight (54.6 lb/bu) and TKW (231 g), higher fat content (5.7%) and fiber content (2.9%). QPM has better kernel characteristics than opaque-2 and is comparable to FGM, but keeping the improved nutritional value of higher lysine and tryptophan content from opaque-2. Comparing QPM to original opaque-2 previously reported, it is clear there has been a major improvement in kernel properties.

Chemical composition

Moisture, protein, fat and fiber content are shown in Table IX. Protein content ranged from 10.4 % to 12.5%. QPM samples had higher protein content than FGM

TABLE VII
Yellow Food Grade Maize and Yellow Quality Protein Maize Color (L* a* b*)[a]

Sample[d]	Color[c]		
	L*	**a***	**b***
Y-FGM 1	62.9 [b]	8.2 [b]	31.8 [a]
Y-FGM $\bar{x}$	**62.9 [B]**	**8.2 [A]**	**31.8 [A]**
Y-QPM 1	64.1[a]	7.5 [c]	32.3 [a]
Y-QPM 2	64.6 [a]	8.9 [a]	31.7 [ab]
Y-QPM 3	64.6 [a]	8.0 [b]	30.6 [b]
Y-QPM $\bar{x}$	**64.9 [A]**	**8.1 [A]**	**31.4** [A]
LSD[b]	1.2	0.5	1.1
LSD $\bar{x}$	**0.99**	**0.6**	**1.0**

[a] Means in the same column and with the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue).
[d] Y = yellow; FGM = food grade maize; QPM = quality protein maize.

TABLE VIII
White Food Grade Maize and White Quality Protein Maize Color (L* a* b*)[a]

Sample[d]	Color[c]		
	L*	a*	b*
W-FGM 1	68.7 ^{bc}	0.7^{e}	19.5^{e}
W-FGM 2	70.5^{a}	0.9^{d}	20.1^{d}
W-FGM $\bar{x}$	**69.13^{A}**	**0.8^{B}**	**19.8^{B}**
W-QPM 1	69.7 ^{b}	3.0^{a}	25.1^{a}
W-QPM 2	68.5 ^{bc}	2.4^{b}	24.3^{b}
W-QPM 3	66.5^{d}	1.9^{c}	19.5^{e}
W-QPM $\bar{x}$	**68.0 ^{B}**	**2.4 ^{A}**	**23.0 ^{A}**
W-HPC	67.8^{c}	1.0^{d}	22.6^{c}
W-HPC $\bar{x}$	**67.7^{B}**	**1.0^{B}**	**22.6^{A}**
LSD[b]	1.1	0.18	0.5
LSD $\bar{x}$	**1.0**	**0.27**	**1.33**

[a] Means in the same column and with the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue).
[d] W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

TABLE IX
Food Grade Maize, Quality Protein Maize and High Protein Corn Kernel Chemical Composition[ab]

Sample[e]	Moisture (%)	Protein[d] (%)	Fat (%)	Fiber (%)
Y-FGM	12.0 [bc]	11.17 [e]	3.17 [ef]	1.96 [e]
W-FGM 1	12.3 [b]	11.36 [de]	3.28 [def]	2.15 [d]
W-FGM 2	11.4 [cd]	11.49 [de]	3.25 [ef]	2.58 [a]
FGM $\bar{X}$	**11.9 [B]**	**11.34 [B]**	**3.23 [A]**	**2.23 [A]**
Y-QPM 1	10.2 [e]	12.01 [cb]	3.10 [f]	2.49 [ab]
Y-QPM 2	10.1 [d]	12.55 [a]	3.06 [f]	2.61 [a]
Y-QPM 3	10.2 [e]	12.30 [ab]	3.80 [bc]	2.35 [c]
W-QPM 1	11.0 [d]	12.34 [ab]	4.06 [ab]	2.60 [a]
W-QPM 2	11.1 [d]	12.53 [a]	4.06 [ab]	2.21 [d]
W-QPM 3	13.2 [a]	11.54 [d]	4.15 [a]	2.37 [bc]
QPM $\bar{X}$	**11.0 [B]**	**12.21 [A]**	**3.7 [a]**	**2.43 [A]**
W-HPC	13.4 [a]	10.41 [f]	3.58 [cd]	2.51 [ab]
HPC $\bar{X}$	**13.4 [A]**	**10.41 [C]**	**3.58 [a]**	**2.51 [A]**
LSD[c]	0.5	0.32	0.32	0.13
LSD $\bar{X}$	**1.32**	**0.48**	**0.59**	**0.30**

[a] Means in the same column and with the same font followed by the same letter are not significantly different at 0.05 level.
[b] Results are expressed in dry weight basis.
[c] LSD = Least significant difference for mean separation.
[d] Crude protein %= N X 6.25.
[e] Y = yellow corn; W = white corn ; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

and HPC. QPMs from College Station (Y-QPM 1, Y-QPM, Y-QPM3, W-QPM1 and W-QPM 2) had greater protein content than QPM from CIMMYT (W-QPM 3). HPC had significantly less protein compared to the QPM and FGM. HPC is a hybrid developed by Wilson's Hybrid Co., that yields 1-2% more protein than normal corn grown under similar conditions. It was produced under high yield conditions, which could have also decreased protein content. Since the samples were not grown at the same location, distinct growing conditions such as nitrogen level, type of soil, and environmental conditions could account for the difference in protein content.

Crude fat content ranged from 3.0% to 4.15% (Table IX). In average, QPM had 15% more fat than FGM, which agrees with Sproule (1985) who reported QPM had 18% more fat than FGM. White QPM had the greatest fat content. Yellow QPM had lower fat content than 4.8% reported by Serna-Saldivar et al. (1992a). Crude fiber content ranged from 1.9% to 2.6% (Table IX). In average all samples had similar fiber content.

A comparison between the amino acid profile of FGM and QPM is shown in Table X. W-FGM 2 and W-QPM 3 samples were analyzed. W-QPM 3 had more of the amino acids lysine (45%), tryptophan (39%), arginine (54%), histidine (43%), aspartic acid (15%), glycine (33%) and lower levels of glutamic acid (8%), alanine (19%) and leucine (30%) compared to W-FGM 2. This is consistent with Vasal (2001). The lower level of leucine produced a favorable leucine-isoleucine ratio, which liberates more tryptophan for niacin biosynthesis thus reducing pellagra (Graham et al. 1990). The increased level of lysine and tryptophan significantly increases the nutritional value of QPM and QPM products.

Conclusion

In this experiment the physical and chemical properties of FGM, QPM and HPC were discussed. Kernel properties required for alkaline cooking and dry milling are generally similar (Rooney and Suhendro 2001). QPM, FGM and HPC analyzed had excellent kernel characteristics for alkaline cooking and dry milling.

QPM had similar test weight, kernel size and density compared to FGM. QPM kernel size was larger than previously reported, therefore QPM kernel size has been increased. Among QPM varieties QPM from CIMMYT (W-QPM-3) was denser and harder. QPM protein quality and quantity was superior to FGM since it had significantly ($P > 0.05$) more protein with 45% more lysine and 38% more tryptophan content.

HPC had the greatest kernel size, with slightly softer endosperm and similar density and test weight compared to FGM. Even though HPC usually contains 1-2% points more protein than FGM grown under similar conditions, it had the lowest protein content. Because our corn samples were not from the same location, differences in environment and growing conditions may have affected protein content. This explains why HPC had the lowest protein content.

QPM had acceptable kernel characteristics with a greater protein quality and quantity compared to FGM and HPC; therefore QPM has an excellent potential in the healthy food market and is an excellent option in countries where maize is a staple food.

TABLE X
Amino Acid Content of White Food Grade Maize (W-FGM) and White Quality Protein Maize (W-QPM).

Amino Acid	% Relative Std. Dev.[b]	W-FGM 2	W-QPM 3
		mg/ 100 g protein	mg/100 g protein
Lysine[a]	0.70	2.83	4.10
Tryptophan[a]	1.64	0.68	0.95
Hydroxyproline	1.95	0.49	0.32
Aspartic Acid	1.06	6.04	6.93
Threonine[a]	0.74	3.31	3.68
Serine	1.40	3.90	3.99
Glutamic Acid	1.01	18.42	16.91
Proline	1.67	8.38	9.03
Lanthinine	0.26	0.10	0.00
Glycine	0.76	3.80	5.04
Alanine	0.68	7.41	5.99
Cysteine	0.64	2.34	3.15
Valine[a]	0.53	4.97	5.67
Methinine[a]	0.99	2.14	1.79
Isoleucine[a]	0.48	3.41	3.05
Leucine[a]	0.49	11.99	8.40
Tyrosine	0.44	2.92	2.63
Phenyalanine[a]	0.55	4.68	3.89
Histidine	0.83	3.02	4.31
Arginine	1.36	4.58	7.04

[a] Essential amino acid, which means it can not be synthesized by the human body.
[b] % Relative standard deviation of the amino acid standard used.

CHAPTER V

PRELIMINARY EVALUATION OF ALKALINE COOKING PROPERTIES: RESULTS AND DISCUSION

The objective of this experiment was to evaluate the alkaline-cooking properties of quality protein maize (QPM), high protein corn (HPC) and food grade maize (FGM). Samples included three yellow QPMs, three white QPMs, one HPC, one white FGM and one yellow FGM. To evaluate pericarp removal, samples were alkaline-cooked for 20 min, stained with the May-Gruenwald dye and evaluated subjectively (1 = all pericarp was removed to 5= none of the pericarp was removed). To obtain the optimum cooking time, samples were alkaline-cooked for 0, 15, 30 and 45 min and steeped for 12 hr. Samples were analyzed for moisture uptake and dry matter losses.

Pericarp removal

Corn varieties had different pericarp removal values after 20 min of alkaline cooking without steeping (Table XI and Appendix C). FGM had better pericarp removal followed by W-HPC and QPM, this agrees with Serna-Saldivar et al. (1992a) who reported that QPM had less pericarp removal than FGM. Among QPMs from College Station, yellow QPM had better pericarp removal than white QPM. This also agrees with Serna-Saldivar et al. (1992a) who reported better pericarp removal for yellow QPM compared to white QPM. Among QPM samples, W-QPM 3 had the most pericarp removed.

Removal of pericarp during alkaline cooking is important because its presence in the masa affects the product color, texture, processing properties and over all dry matter losses (Rooney and Bockholt 1987). Ease of pericarp removal during alkaline cooking depends on the type of alkali, its concentration, cooking duration, temperature, corn genotype and growing environment (Serna-Saldivar et al. 1991).

TABLE XI
Effect of Alkaline-Cooking Time on Nixtamal Moisture and Dry Matter Losses (DML)[a]

Sample[d]	Pericarp removal[c]	0 min		15 min		30 min		45 min	
		Moisture (%)	DML (%)	Moisture (%)	DML (%)	Moisture (%)	DML (%)	Moisture (%)	DML (%)
FGM $\bar{X}$	1.2^{a}	44.6^{c}	4.15^{a}	49.6^{c}	5.45^{a}	51.8^{b}	6.3^{b}	54.4^{a}	8.8^{ab}
Y-QPM $\bar{X}$	3.8^{c}	45.1^{c}	3.0^{b}	47.6^{f}	3.8^{b}	49.5^{c}	4.0^{c}	55.0^{a}	8.4^{a}
W-QPM $\bar{X}$	3.3^{c}	48.5^{a}	2.4^{c}	51.6^{b}	5.6^{a}	52.8^{b}	6.9^{ab}	56.5^{a}	8.4^{ab}
QPM $\bar{X}$	3.6^{c}	46.8^{b}	2.7^{bc}	49.6	4.7^{b}	51.1^{b}	5.4^{bc}	55.8^{a}	8.4^{ab}
HPC $\bar{X}$	2.3^{b}	46.8^{b}	3.3^{b}	53.2^{a}	6.6^{a}	54.4^{a}	8.3^{a}	55.9^{a}	9.7^{a}
LSD[b] $\bar{X}$	**0.84**	**0.78**	**0.65**	**1.10**	**1.25**	**1.51**	**1.40**	**2.04**	**3.9**
Mean	**2.9^{c}**	**46.32^{D}**	**3.23^{C}**	**49.99^{c}**	**5.15^{b}**	**51.36^{B}**	**5.84^{b}**	**54.98^{A}**	**7.70^{a}**
LSD_{time}	**---**				**1.24**				
LSD_{DML}					**1.18**				

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Pericarp removal evaluation was done cooking the samples 20 min and without steeping.
[d] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn. Results for all samples are shown in Appendix C.

Pericarp remnants are not a significant problem for table tortilla production since the pericarp is a source of hydrocolloids which improve pliability and prevent or retard staling of the tortilla and increase fiber content. However, it is important for tortilla chip production, where some processors want complete removal since it accumulates on the wires of the sheeter (Serna-Saldivar et al. 1991).

Preliminary alkaline cooking

Moisture content increased with increasing cooking time for all corn samples (Table XI, Fig. 10 and Fig. 11). Yellow QPMs absorbed moisture slower than white QPMs and had less dry matter losses through cooking time. White QPM had lower TKW, the smaller kernel size could have increased heat transfer, thus increasing moisture uptake. Comparing FGM versus QPM, yellow FGM absorbed moisture faster than yellow QPMs, the slower pericarp removal probably decreased moisture uptake through cooking time. On the other hand white FGM that absorbed moisture slower than white QPMs and HPC. At 45 min of cooking, all samples were overcooked and moisture content ranged from 52.6% to 56.5%. Lime-cooking contributed to water uptake in the kernel, while the 12 hr of steeping contributed to the water redistribution and softened the kernel structure (Gomez et al. 1991b).

Dry matter losses (DML) increased with increasing cooking time for all samples (Table XI, Fig. 12 and Fig. 13). White QPM had higher DML during cooking compared to yellow QPM. Serna-Saldivar et al. (1993) found that cooking time, pericarp removal and hardness were correlated with DML. Dry matter losses in the nejayote (waste water) are mainly composed of pericarp, starch, protein and germ solubles and increase when softer corn is processed (Pflugfelder et al. 1988a). Khan et al. (1982) found that DML increased with cooking time, but DML during steeping accounted for much of the loss.

Optimum cooking time

Nixtamal optimum moisture was 50% because the masa has acceptable plasticity and machinability (Gomez et al. 1991b). Cooking time necessary to obtain

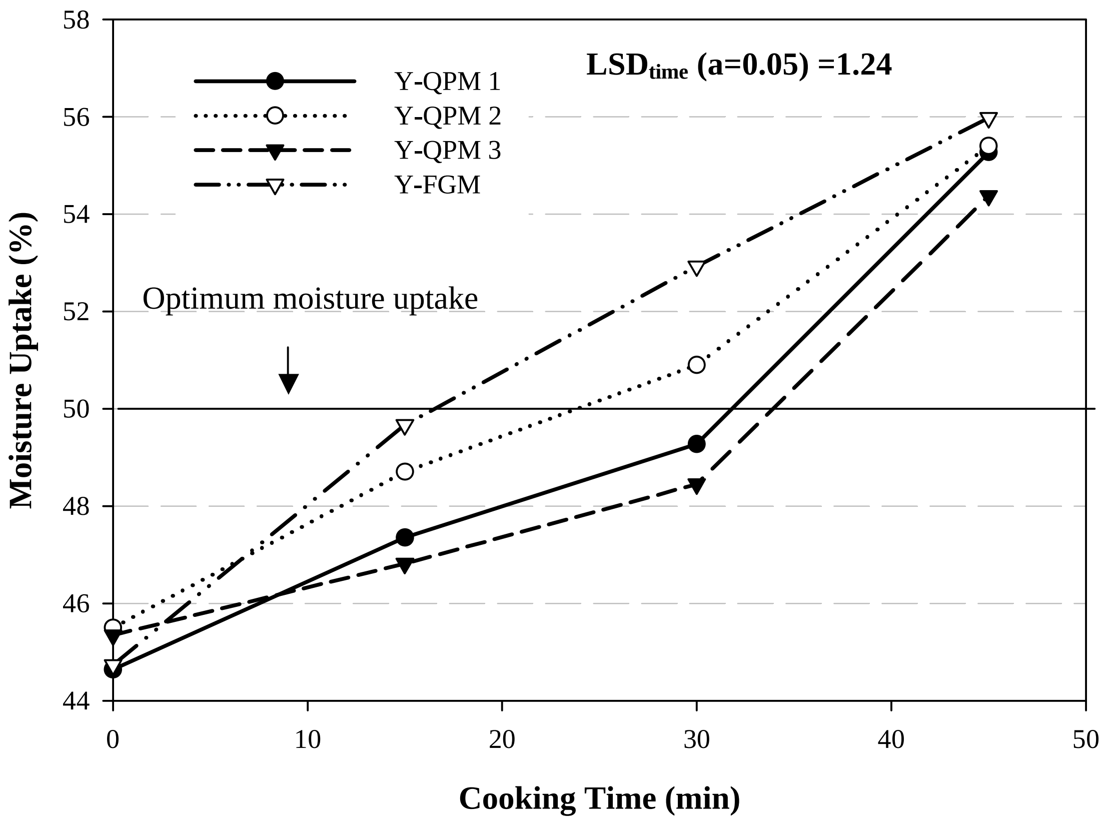

Fig. 10. Water uptake during cooking for three yellow quality protein maize (Y-QPM) and one yellow food grade maize (Y-FGM). LSD = Least significant difference for mean separation. LSD (α=0.05) 0 min = 1.1; LSD (α=0.05) 15 min = 1.1; LSD (α=0.05) 30 min = 1.5; LSD (α=0.05) 45 min = 1.6.

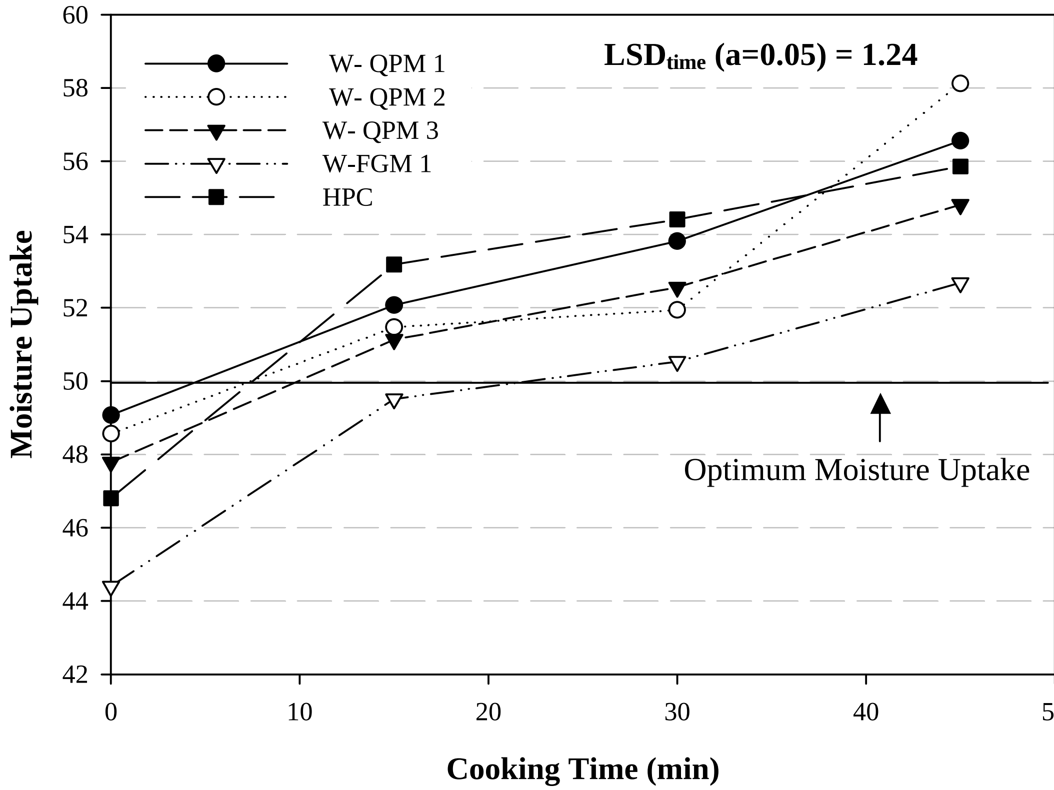

Fig. 11. Water uptake during cooking for three white quality protein maize (W-QPM), one white high protein corn (W-HPC) and one white food grade maize (W-FGM). LSD = Least significant difference for mean separation. LSD (α=0.05) 0 min = 1.1; LSD (α=0.05) 15 min = 1.1; LSD (α=0.05) 30 min = 1.5; LSD (α=0.05) 45 min = 1.6.

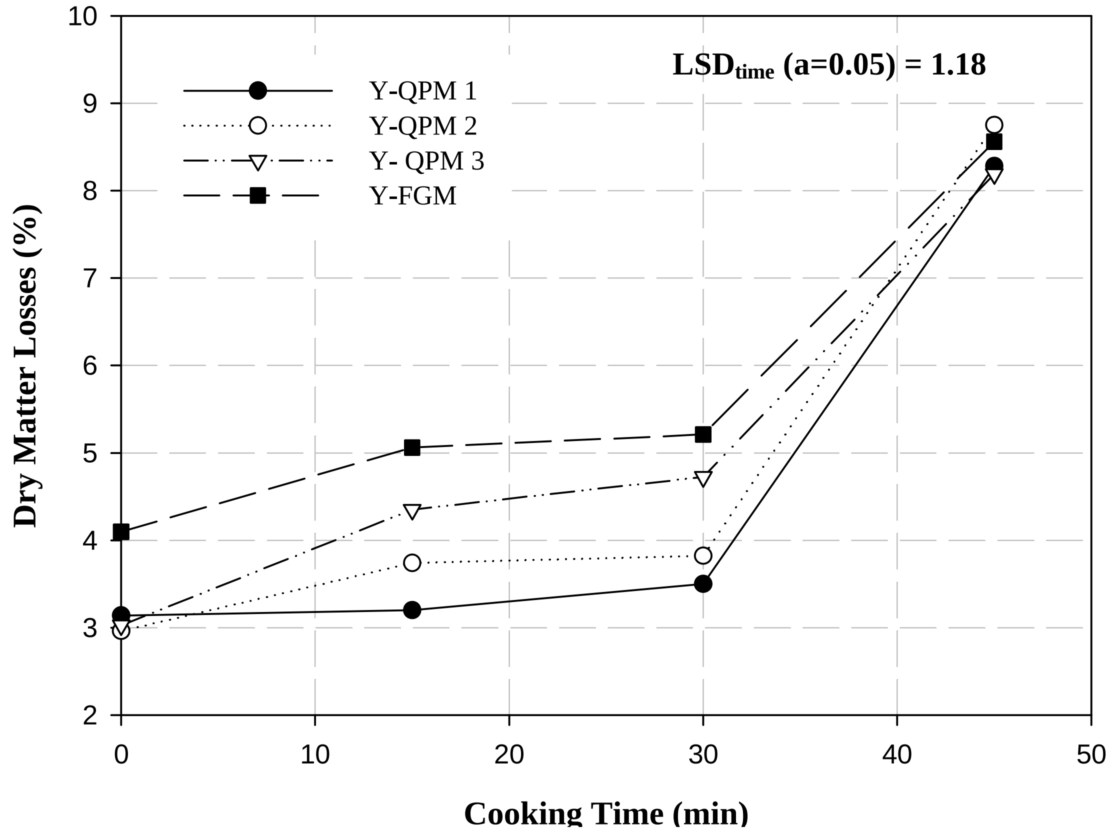

Fig. 12. Dry matter losses during alkaline-cooking for three yellow quality protein maize (Y-QPM) and one yellow food grade maize (Y-FGM). LSD = Least significant difference for mean separation. LSD (α=0.05) 0 min = 0.7; LSD (α=0.05) 15 min = 1.4; LSD (α=0.05) 30 min = 0.9; LSD (α=0.05) 45 min = 1.5.

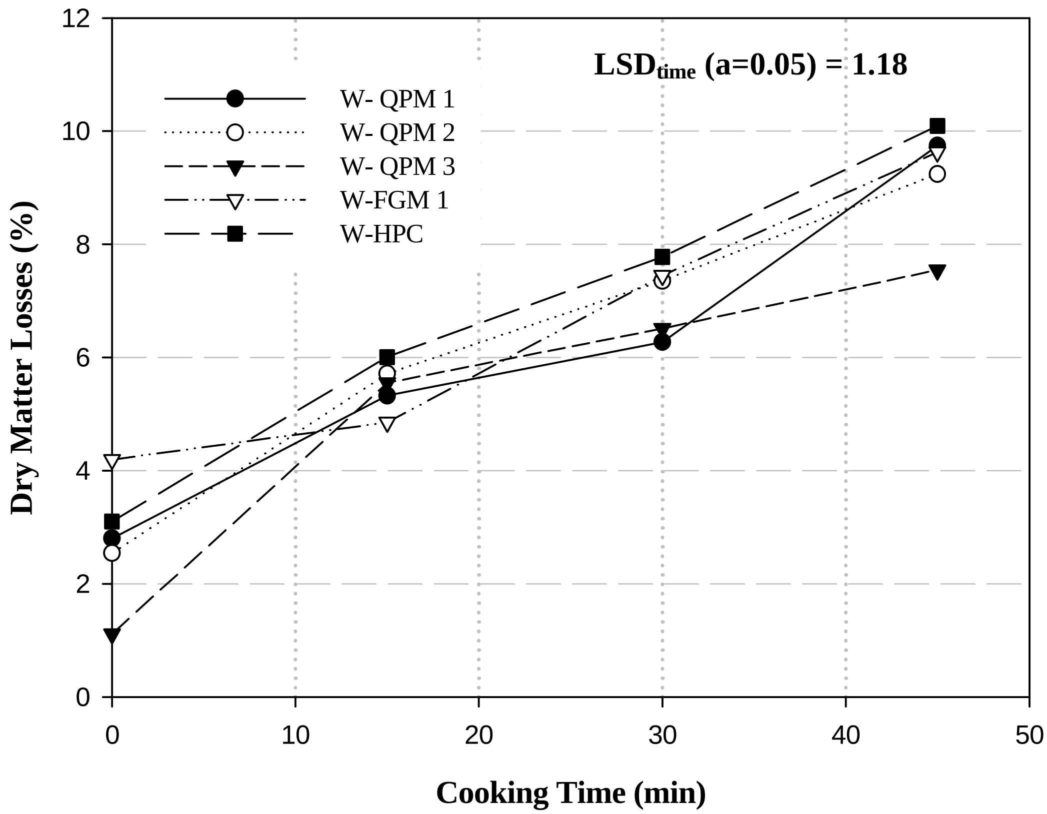

Fig. 13. Dry matter losses during alkaline-cooking for three white quality protein maize (W-QPM), one white high protein corn (W-HPC) one white food grade maize (W-FGM). LSD = Least significant difference for mean separation. LSD (α=0.05) 0 min = 0.7; LSD (α=0.05) 15 min = 1.4; LSD (α=0.05) 30 min = 0.9; LSD (α=0.05) 45 min = 1.5.

TABLE XII
Food Grade Maize, Quality Protein Maize and High Protein Corn Optimum Cooking Time, Dry Matter Losses and Pericarp Removal[a].

SAMPLE[d]	Optimum cooking time (min)	Dry Matter Losses (DML)[b] (%)	Pericarp removal[e]
Y-FGM	16.5	5.0	1.0 [a]
W-FGM 1	20.6	5.8	1.0 [a]
FGM $\bar{X}$	**18.6**	**5.4**	**1.0 [B]**
Y-QPM 1	32.3	4.2	1.2 [a]
Y-QPM 2	24.7	3.8	1.2 [a]
Y-QPM 3	34.0	5.8	1.2 [a]
Y-QPM $\bar{X}$	**30.3**	**4.6**	**1.2 [AB]**
W-QPM 1	3.5	3.8	1.5 [a]
W-QPM 2	7.0	4.0	1.5 [a]
W-QPM 3	9.0	3.8	1.0 [a]
W-QPM $\bar{X}$	**6.5**	**3.9**	**1.3 [AB]**
QPM $\bar{X}$	**18.4**	**4.2**	**1.3 [AB]**
W-HPC	7.0	4.2	1.5 [a]
HPC $\bar{X}$	**7.0**	**4.2**	**1.5 [A]**
LSD[c]	--	--	0.51
LSD $\bar{X}$	**--**	**--**	**0.38**

[a] Optimum cooking time was the time required to obtain 50% nixtamal moisture and was obtained with linear regression from Fig. 10 and Fig. 11.
[b] Dry matter losses at the optimum cooking time.
[c] LSD = Least significant difference for mean separation.
[d] Means in the same column and with the same font followed by the same letter are not significantly different at 0.05 level.
[e] Pericarp removal evaluation was done at the optimum cooking time and 12 hr of steeping.

50% moisture in the nixtamal ranged from 3.5 to 34 min (Table XII). Yellow QPMs required longer cooking time compared to white QPMs and yellow FGM. HPC cooked faster than the control and most of the QPMs. This agrees with Strissel and Stiefel (2002) who reported HPC optimum cooking time was shorter compared to FGM. Ramírez-Wong et al. (1994) reported FGM required cooking times between 20 and 55 min to produce a masa with good characteristics. These cooking times are more than twice the ones required for white QPM and HPC, and within the range for yellow QPM. HPC decreased in cooking time is significant, since it has a significant larger kernel. HPC had lower protein content which could have facilitated water absorption by the starch granule. Strissel and Stiefel (2002) reported HPC to 50% amylose content compared to 25% in regular corn. Higher amylose content increased the amorphous zones inside the starch granule. Water could penetrate easier and faster in the amorphous zones, since there was an increase in the amorphous zones, this could explain the decreased cooking time. Amylose and amylopectin were not analyzed in this study, so further research is requires to clarify the decreased cooking time.

Dry matter losses (DML) ranged from 3.8 to 5.8 % (Table XII). White QPM samples had less DML at the optimum cooking time than yellow QPM and FGM because of the shorter exposure to boiling temperature. QPM had less dry matter losses probably because the pericarp was more difficult to remove than FGM. Wichser (1966) reported pericarp of opaque-2 maize more firmly adhered to the endosperm than FGM during dry milling. QPM DML could also be affected by the slower pericarp removal during cooking time compared to FGM (Fig 14).

Dry matter losses for all samples in this experiment were below 6%. Pflugfelder et al. (1988a) reported higher DML in a commercial process for masa production of 8.5 to 12.5%. Bressani et al. (1958) also reported higher DML of 17.1% for white corn and of 15.4% for yellow corn using traditional cooking in rural homes in Guatemala. Khan et al. (1982) found losses of 7-9% for commercial processing, and 11 to 13% for the traditional cooking. Both results are higher than DML values found in this experiment. Milder cooking was used during this experiment compared to industrial processes, which may explain the decrease in DML. Also the use of corn without broken or cracked kernels might have decreased DML in this experiment.

Pericarp was removed successfully at the optimum cooking time for all corn varieties. QPM had significantly better pericarp removal at the optimum cooking time compared to the preliminary test (Fig. 14). Therefore steeping time affected pericarp removal. The preliminary test is a quick tool to evaluate pericarp removal within corn varieties since it requires 20 min of cooking compared the evaluation at optimum cooking time that requires 12 hr of steeping. More accurate pericarp removal evaluation can be obtained when simulating the processing conditions, since some corn varieties respond to steeping.

Conclusion

Optimum cooking time required to obtain 50% nixtamal moisture was obtained. During alkaline cooking, HPC absorbed water faster than QPM and FGM, therefore it can be cooked in shorter time, decreasing energy costs. The decrease in HPC cooking time is very significant since it has a larger kernel size. White QPM required shorter cooking time and had less dry matter losses compared to FGM. Yellow QPM required longer cooking time than FGM but also had less dry matter losses. All corn varieties had excellent pericarp removal at the optimum cooking time, but pericarp was removed slower in QPMs than in FGM. The slower pericarp removal in QPM may be involved in decreasing QPM dry matter losses during alkaline cooking. Shorter cooking time and low dry matter losses could be beneficial to tortilla producers by decreasing energy and sewage costs and decreasing grain loss. Therefore the use of some QPM varieties may decrease sewage and energy cost during alkaline cooking.

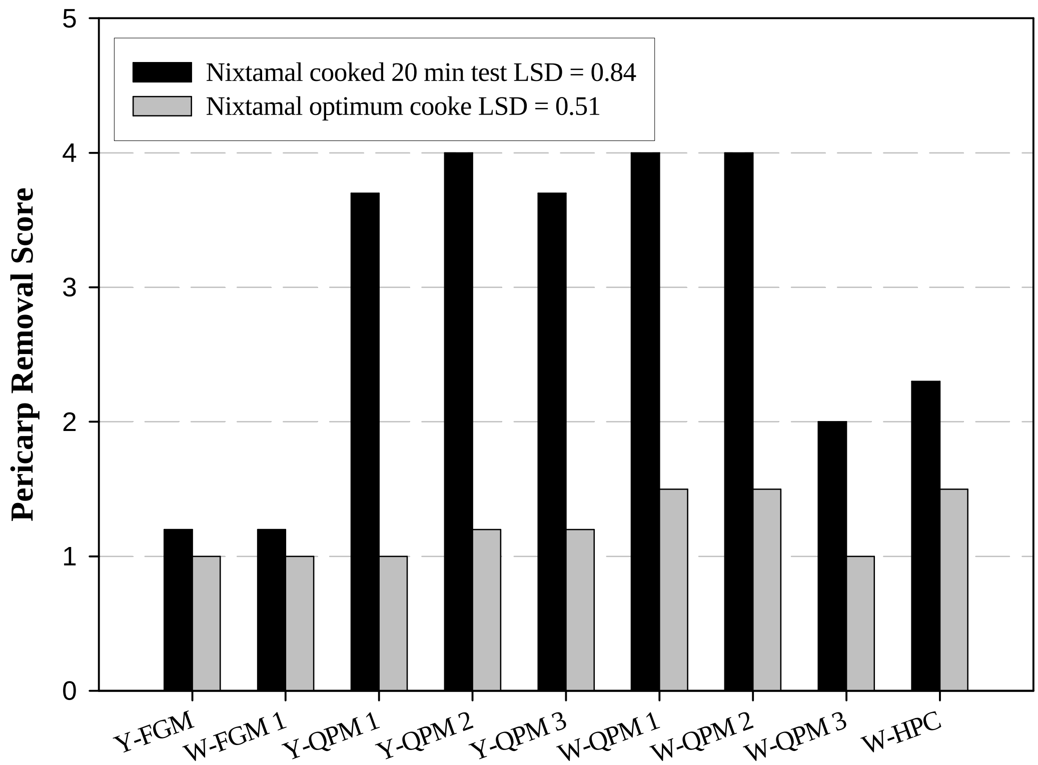

Fig. 14. Pericarp removal of corn alkaline-cooked 20 min with no steeping and cooked at optimum cooking time. Score: 1 = all pericarp was removed, 5=none of the pericarp was removed. LSD = Least significant difference for mean separation at a 0.05 level.

CHAPTER VI

ELABORATION AND EVALUATION OF TABLE TORTILLAS: RESULTS AND DISCUSION

The objective of the experiment was to evaluate and compare nixtamalization and tortilla processing from three yellow quality protein maize (Y-QPM), three white quality protein maize (W-QPM), one white high protein corn (W-HPC), one yellow food grade maize (Y-FGM) and one white food grade maize (W-FGM).

Tortillas were processed in the Texas A&M Pilot Plant in two (15 Kg) separate batches, one with yellow corn and the other one with white corn. Samples (2.5 Kg) were placed in perforated nylon bags. Each corn variety was cooked at its optimum cooking time (previously determined in Chapter V) in a 1% lime solution as described in Table XIII. After cooking the steam was cut off and the corn was steeped for 12 hr. The nixtamal was hand washed and evaluated for moisture uptake dry matter losses and nixtamal shear cell force. Afterward, the clean nixtamal was ground in a stone grinder; a solution with 0.5% of fumaric acid and 0.5% of potassium sorbate in 300 mL of distilled water was added during grinding. Masa was objectively evaluated for particle size distribution, and color (L*, a* and b*) and subjectively evaluated for stickiness, hardness and machinability.

The masa was sheeted and formed continuously into 30 g ± 1 g tortilla discs and continuously backed for 60 sec in a gas-fired three tier oven at 320, 270 and 250°C for the top, middle and bottom tier. Tortillas were conveyed into a three-stage cooling rack for 2 min and equilibrated at room temperature for 10 min, weighed and stored in low-density polyethylene bags at 25°C for up to 120 hr. Tortillas were evaluated for 1-D extensibility, rollability and pliability. Yields of nixtamal, masa and tortillas were determined for each corn variety.

TABLE XIII
Food Grade Maize, Quality Protein Maize and High Protein Corn Alkaline Cooking Conditions

SAMPLE[a]	Cooking time[b] (Min)	Steeping time (hr)	Water/grain	$Ca(OH)_2$ (% grain wt)
Y-FGM	16.5	12	3:1	1
W-FGM 1	20.6	12	3:1	1
Y-QPM 1	32.3	12	3:1	1
Y-QPM 2	24.7	12	3:1	1
Y-QPM 3	34.0	12	3:1	1
W-QPM 1	3.5	12	3:1	1
W-QPM 2	7	12	3:1	1
W-QPM 3	9	12	3:1	1
W-HPC	7	12	3:1	1

[a] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.
[b] Cooking time was determined in Chapter V.

Nixtamal properties

Nixtamal moisture uptake, dry matter losses (DML) and nixtamal shear cell force (N) and work (Nm) are shown in Table XIV. Nixtamal moisture content was between 50.09 and 54.05% (Table XIV). HPC nixtamal moisture content was significantly higher than the rest of the samples. From Chapter V, HPC absorbed moisture faster than the rest of the samples during alkaline cooking (Fig. 11), therefore HPC moisture uptake was more sensitive to variations during processing. This agrees with Strissel and Stiefel (2002) who reported HPC cooked faster than FGM. Yeggy (2000), also obtained HPC nixtamal with greater moisture content compared to FGM; during the experiment HPC was cooked 10 min while in this

TABLE XIV
Food Grade Maize, Quality Protein Maize and High Protein Corn Nixtamal Properties[a]

SAMPLE[c]	Moisture uptake (%)	DML (%)	Nixtamal shear cell	
			Force Peak (N)	Work (Nm)
Y-FGM	50.96 [b]	8.29 [cd]	322 [g]	11.9 [g]
W-FGM 1	50.09 [c]	8.51 [bc]	585 [d]	20.9 [d]
FGM $\bar{X}$	**50.5 [C]**	**8.40 [B]**	**453 [CD]**	**16.4 [D]**
Y-QPM 1	52.03 [b]	7.68 [e]	467 [e]	19.6 [e]
Y-QPM 2	52.16 [b]	7.20 [f]	528 [c]	22.4 [c]
Y-QPM 3	52.29 [b]	8.69 [b]	482 [e]	19.7 [e]
Y-QPM $\bar{X}$	**52.16 [B]**	**7.86 [BC]**	**494 [C]**	**20.6 [C]**
W-QPM 1	52.87 [bc]	7.14 [f]	616 [b]	24.6 [b]
W-QPM 2	51.21 [bc]	8.03 [de]	728 [a]	30.0 [a]
W-QPM 3	51.05 [bc]	7.16 [f]	609 [b]	24.6 [b]
W-QPM $\bar{X}$	**51.27 [B]**	**7.47 [C]**	**651 [A]**	**26.4 [A]**
QPM $\bar{X}$	**51.93 [B]**	**7.66 [BC]**	**572 [B]**	**23.5 [B]**
W-HPC	54.06 [a]	9.88 [a]	416 [f]	16.0 [f]
HPC	**54.06 [A]**	**9.88 [A]**	**416 [D]**	**16.0 [D]**
LSD[b]	1.72	0.26	35	1.0
LSD $\bar{X}$	**1.05**	**0.81**	**53**	**1.9**

[a] Means in the same column and the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

experiment HPC was cooked 7 min. Nixtamal moisture content from all samples was acceptable for grinding into masa suitable for table tortillas.

DML values were between 7.07 and 9.88% (Table XIV). These values were higher compared to values in the preliminary trial (Chapter V). DML could have increased because of a change in the washing method, since this experiment was larger scale (2.5 Kg per sample compared to 50 g in the preliminary trials).

DML are mainly composed of pericarp remnants, so a change in the washing procedure could have increased pericarp removal affecting overall DML. QPM had less DML, probably due to the pericarp more closely adhered to the endosperm compared to FGM. Wichser (1966) reported that pericarp of opaque-2 maize was more firmly adhered to the endosperm than FGM. Even though at the optimum cooking time pericarp was well removed for all samples, in the preliminary pericarp removal test (Fig. 14) pericarp was less removed for QPM kernel than FGM kernel, consequently affecting DML. White QPM had less DML compared to yellow QPM. This could be because of the shorter exposure to boiling temperature.

Pflugfelder et al. (1988a) reported DML in a commercial process for production of masa of 8.5 to 12.5%. DML in this experiment similar to reported by Khan et al. (1982), who found losses of 7-9% for commercial processing, and lower than reported using the traditional method, 11 to 13%.

Nixtamal shear cell force and work are shown in Table XIV. Nixtamal shear cell force ranged between 321.64 and 728.26 N. Work required to extrude nixtamal through a die was between 11.90 and 29.97 Nm. W-HPC required less force followed by FGM and QPMs. This could be caused by a higher moisture content and lower protein content.

Masa particle size distribution

Nixtamal was stone-ground into masa for table tortillas. Masa particle size distribution is shown in Table XV. Friction between the stone grinder and nixtamal

TABLE XV
Food Grade Maize, Quality Protein Maize and High Protein Corn Masa Particle Size Distribution[a]

SAMPLE[c]	Coarse >850 µm (%)	Medium <850 µm >150µm (%)	Fine <150 µm (%)
Y-FGM	16.3 a	23.9 d	50.1 c
W-FGM 1	15.7 ab	34.5 ab	49.8 c
Y-QPM 1	13.1 d	36.2 a	50.7 bc
Y-QPM 2	12.8 d	34.8 ab	52.4 bc
Y-QPM 3	15.5 b	33.0 bc	51.5 bc
W-QPM 1	14.3 c	35.5 ab	50.2 bc
W-QPM 2	14.7 c	31.0 c	54.3 ab
W-QPM 3	12.5 d	35.1 ab	52.4 bc
W-HPC	11.3 e	30.6 c	58.1 a
LSD[b]	**0.74**	**3.19**	**4.15**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

gives the masa final particle size (Ramirez-Wong et al. 1994). Fine fraction was between 49.8 and 58.1%. According to Pflugfelder et al. (1988b), this fraction (<150 µm) is composed of free starch, approximately 90% of the free starch granules, and dissolved solids, in the same study it was suggested that masa free starch, dissolved solids, and free lipid are the primary determinants of the texture, flavor, as well as the masa flexibility.

Results in this experiment agree with Pflugfelder et al. (1988b) who reported yields of 41.6 and 64.9% free starch and dissolved solids in commercial processes and with Serna-Saldivar et al. (1992a) (1992) who reported values were between 57.5 and 58.6%. Pflugfelder et al. (1988b) suggested that broken and fragmented kernels significantly contributed to the extent of starch gelatinization in the masa free starch fraction. In this experiment the grain was cleaned prior to processing so broken kernels did not affect the starch fraction. Khan et al. (1982) reported overcooking of masa resulted in a finer particle size distribution. During this experiment, nixtamal was not over cooked, but samples with higher moisture content had greater soluble fraction and lower coarse fraction.

Coarse fraction (>250 µm) was between 11.13 and 16.3 %, this fraction is composed primarily of germ and tip cap and endosperm chunks (Pflugfelder et al. 1988b). HPC had less coarse particles, this could be caused by greater nixtamal moisture, and softer nixtamal texture (low nixtamal shear cell force). Grinding disrupts the swollen gelatinized starch granules and distributes the hydrated starch and protein around the ungelatinized portion of the corn endosperm (Rooney and Serna-Saldivar 1987).

Medium fraction (<850 µm >150 µm) were between 23.9 and 36.2%. The medium fraction is composed of smaller parts of endosperm; approximately 63% of starch (Pflugfelder et al. 1988b). During this experiment, according to the masa moisture content and particle size distribution, it can be implied that nixtamal was ground properly and differences in masa and tortilla properties could be attributed to the grain variety.

Masa textural characteristics

Masa texture is one of the most critical aspects of the corn tortilla process. When the masa has the appropriate texture, it can be easily shaped, on the other hand, masas with non-cohesive or sticky texture will be inadequate for tortilla formation (Ramirez-Wong et al. 1993). Masa texture is determined by corn variety, endosperm texture and type, drying conditions, and soundness of the corn, as well as the water uptake, and degree of starch gelatinization during alkaline cooking (Bedolla and Rooney 1982).

Masa moisture ranged between 53.71 and 56.23% (Table XVI). Masa typically requires moisture content above 51% for optimum tortilla processing (Strissel and Stiefel 2002). Therefore all masas had adequate moisture level. Masa from Y-QPM 1 had the lowest moisture content even though nixtamal moisture was similar to most of the samples. During grinding less water was added to this sample because it was sticky and more water would have made it stickier and hard to process into tortilla.

Masa subjective evaluation for hardness, machinability and stickiness is shown in Fig. 15. According to Ramirez-Wong et al. (1994) the best masa texture should be that giving good handling or machinability in the sheeting and cutting rollers, producing a higher tortilla yield, and producing good firmness and rollability in the tortillas. Hardness of the masa was related to moisture content from nixtamal and masa (R^2=0.897)(Appendix D). This confirms previous work by Ramirez-Wong et al. (1994) who reported that hardness decreases as the moisture level increases regardless of its particle size distribution. Masas with greater moisture content were generally stickier This agrees with Ramirez-Wong et al. (1994) who reported that adhesiveness of the masa increases with increasing the moisture content. HPC masa was stickier, probably due to a greater proportion of gelatinized starch granules that form a glue-like film as swollen starch granules are dispersed during grinding, which agrees with previous work on HPC reported by Yeggy (2000). Y-QPM 1 was the exception, it was the stickiest masa even though it had the lowest moisture content. Since the rest of the masas had greater moisture, stickiness of the masa was not

TABLE XVI
Food Grade Maize, Quality Protein Maize and High Protein Corn Masa Moisture and pH[a]

SAMPLE[c]	pH	Moisture (%)
Y-FGM	4.97 ^{b}	56.23 ^{a}
W-FGM 1	5.15 ^{ab}	54.92 ^{cd}
FGM $\bar{X}$	**5.06 ^{A}**	**55.58 ^{AB}**
Y-QPM 1	5.03 ^{ab}	53.71 ^{e}
Y-QPM 2	5.15 ^{ab}	55.52 ^{bc}
Y-QPM 3	5.27 ^{ab}	54.36 ^{de}
Y-QPM $\bar{X}$	**5.15 ^{A}**	**54.53 ^{B}**
W-QPM 1	5.45 ^{a}	55.11 ^{bc}
W-QPM 2	5.30 ^{ab}	55.38 ^{bc}
W-QPM 3	5.20 ^{ab}	54.43 ^{d}
W-QPM $\bar{X}$	**5.31 ^{A}**	**54.97 ^{AB}**
QPM $\bar{X}$	**5.23 ^{A}**	**54.75 ^{AB}**
W-HPC	5.06 ^{ab}	55.75 ^{ab}
W-HPC $\bar{X}$	**5.06 ^{A}**	**55.75 ^{A}**
LSD[b]	0.48	0.67
LSD $\bar{X}$	**0.32**	**1.1**

[a] Means in the same column and the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

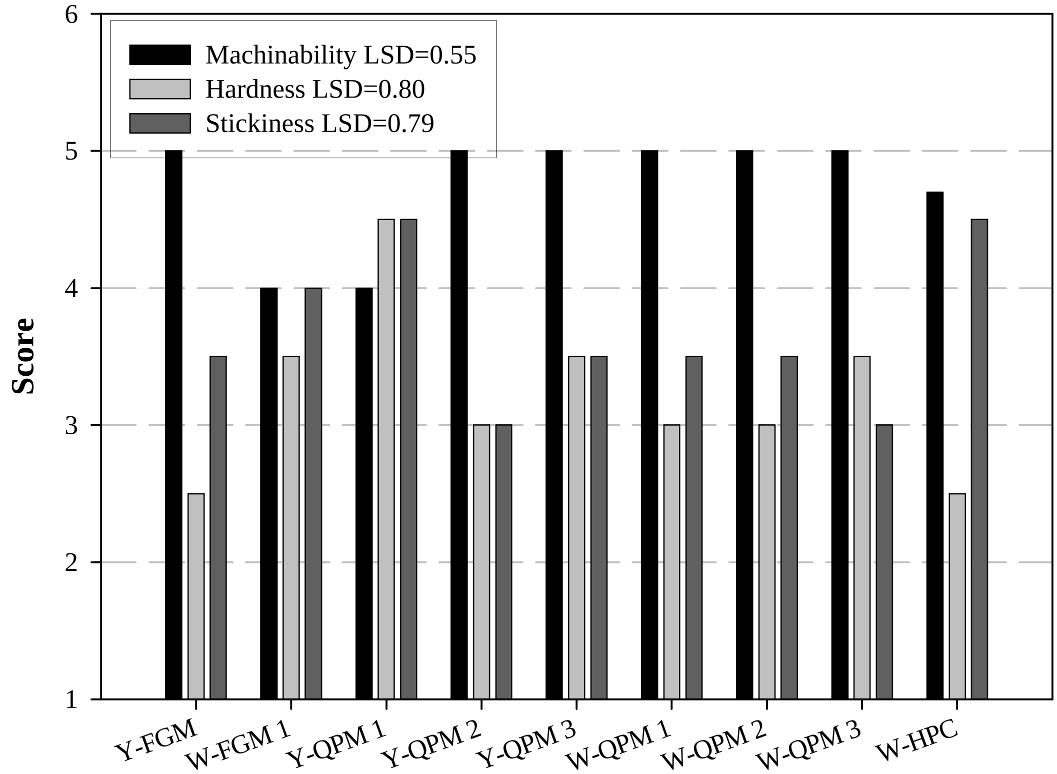

Fig. 15. Masa subjective evaluation for machinability, hardness and stickiness. Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn. Scores: 1 = low, 3 = intermediate and to 5 = high. LSD = Least significant difference for mean separation at 0.05 level.

caused by high moisture content. Y-QPM 1 had similar fine fraction to all samples except W-HPC. Stickiness could have been caused by the increased glutelin content and decreased zein content compared to FGM, which is a characteristic in QPM genotypes (Lasztity 1996). In this experiment protein fraction was not determined. Even though there were some differences in hardness and stickiness, masa from QPM and HPC was successfully processed into tortillas.

Masa color is shown in Table XVII. All masas from yellow corn had similar lightness and were lighter than previously reported by Serna-Saldivar et al. (1992a), who reported values of 70.3 for the yellow FGM masa and 72.5 for yellow QPM masa. Y-FGM masa was more yellow (higher b* value) than masas from Y-QPM. Vasal (2001) reported yellow QPM genotypes to be less yellow than FGM, but no values were reported. All masas from yellow corn were more yellow compared to previous values of 29.2 and 28.0 for Y-FGM and Y-QPM respectively (Serna-Saldivar et al. 1992a). All masas made of white corn were lighter and less yellow than the ones from yellow corn. Sahai et al. (2001) reported color *a* value is influenced by protein content and hardness index when the same lime concentration was used. Yellowness (*b* value) is influenced by cook temperature, cooking time, steeping time and lime concentration. Since all masas had similar pH (Table XVI) yellowness can be attributed to corn variety.

Tortilla evaluation

Tortilla moisture content and color values are shown in Table XVIII. Moisture content varied from 38.46 to 44.89%. Moisture of W-HPC tortilla was similar to the control (W-FGM 1), even though W-HPC masa had greater moisture content than W-FGM 1 masa. W-HPC lost more moisture during baking. The lower protein content in W-HPC might have influenced the moisture loss. In this experiment protein content was inversely related to moisture loss during baking, the greater protein content the lower moisture loss during baking (Appendix D). Tortillas from Y-QPM 1 had the lowest moisture, since the masa also had the lowest moisture content to avoid greater stickiness during sheeting and forming.

TABLE XVII
Food Grade Maize, Quality Protein Maize and High Protein Corn Masa Color (L*, a*, and b)[a]

SAMPLE[c]	Color		
	L *	a *	b *
Y-FGM	79.31 [a]	-0.85 [a]	37.15 [a]
Y-QPM 1	79.46 [a]	-1.87 [b]	32.53 [b]
Y-QPM 2	80.52 [a]	-2.44 [c]	32.69 [b]
Y-QPM 3	80.40 [a]	-2.18 [c]	32.47 [b]
LSD[b]$_{yellow}$	**1.74**	**0.31**	**1.37**
W-FGM 1	83.18 [d]	-0.42 [e]	15.58 [f]
W-QPM 1	83.06 [d]	0.11 [d]	21.02 [c]
W-QPM 2	84.30 [b]	-0.07 [d]	19.18 [d]
W-QPM 3	83.68 [c]	0.05 [d]	15.47 [f]
W-HPC	83.90 [bc]	-0.49 [e]	18.84 [e]
LSD[b]$_{white}$	**0.48**	**0.26**	**0.30**

[a] Means in the same column, within yellow corn and white corn, followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

TABLE XVIII
Food Grade Maize, Quality Protein Maize and High Protein Corn Tortilla Color[a]

SAMPLE[c]	**Moisture (%)**	**Color L ***	**a ***	**b ***
Y-FGM	40.86 c	74.71 a	0.93 a	46.12 a
Y-QPM 1	38.46 d	73.50 b	-0.20 b	38.14 c
Y-QPM 2	44.89 a	73.21 bc	-0.04 b	42.86 b
Y-QPM 3	40.41 c	72.55 c	1.22 a	44.23 ab
LSD[b]	**1.65**	**0.94**	**0.49**	**2.5**
W-FGM 1	42.50 bc	78.46 c	0.09 c	18.01 d
W-QPM 1	43.12 b	76.78 e	1.24 a	26.06 a
W-QPM 2	42.31 bc	77.36 d	0.50 b	24.94 b
W-QPM 3	41.61 bc	79.01 b	0.34 bc	21.81 c
W-HPC	42.35 bc	79.73 a	0.30 bc	18.66 d
LSD[b]	**1.65**	**0.52**	**0.27**	**0.84**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

HPC tortillas were lighter, than the rest of the tortillas (Table XIX). Yellow tortilla from FGM was as yellow as tortilla from Y-QPM-3 but more yellow than the rest of yellow QPMs. Tortillas from white FGM were the less yellow than tortillas from white QPMs. Tortillas had darker color than the raw grain and masa. The darker color of the tortillas compared to the raw grain agrees with work by Sproule (1985). The same author reported L values of 77.9 and 77.3 for white FGM tortilla and white QPM tortilla, these values agree with results found in this experiment. Corn tortilla color is an important characteristic related to consumer acceptability (Sahai et al. 2001).

Rollability scores from 0.5 to 120 hr of storage are shown in Appendix D and scores from 24 to 120 hr of storage are shown in Figure 16. As storage time increased, tortilla became firmer, less flexible and the rollability scores decreased for most of the samples. There was no difference in tortillas stored for up to 24 hr. At 72 hr of storage tortillas from W-HPC were the least rollable ($P < 0.05$). At 120 hr of storage, most of the tortillas made from QPM (Y-QPM 2, Y-QPM 3, W-QPM 2 and W-QPM 3) were more rollable compared to tortillas made of FGM and HPC. Greater rollability score means the tortilla could be rolled with less or none cracks. The use of QPM increased ($P < 0.05$) rollability after 120 hr of storage; therefore tortillas from QPM will have longer shelf stability compared to tortillas from FGM and HPC.

Pliability scores through storage time are shown in Appendix D and from 6 to 120 hr of storage in Figure 17. Differences in pliability were detected after 24 hr of storage. Tortillas from QPM (W-QPM 3, W-QPM 2, Y- QPM 3 and Y-QPM 1) had better pliability than tortillas from FGM and HPC after 24 hr of storage. The same behavior was observed at 120 hr of storage. Better pliability means the tortilla could be folded with the hand and extended with few or no cracks. The use of QPM increase pliability score after 72 hr compared to FGM, this confirms that QPM could increase shelf stability in corn tortillas.

Free lipids may have a tenderizing effect on tortilla texture (Pflugfelder et al. 1988b), since QPM grain had greater lipid content, it is likely that this positively

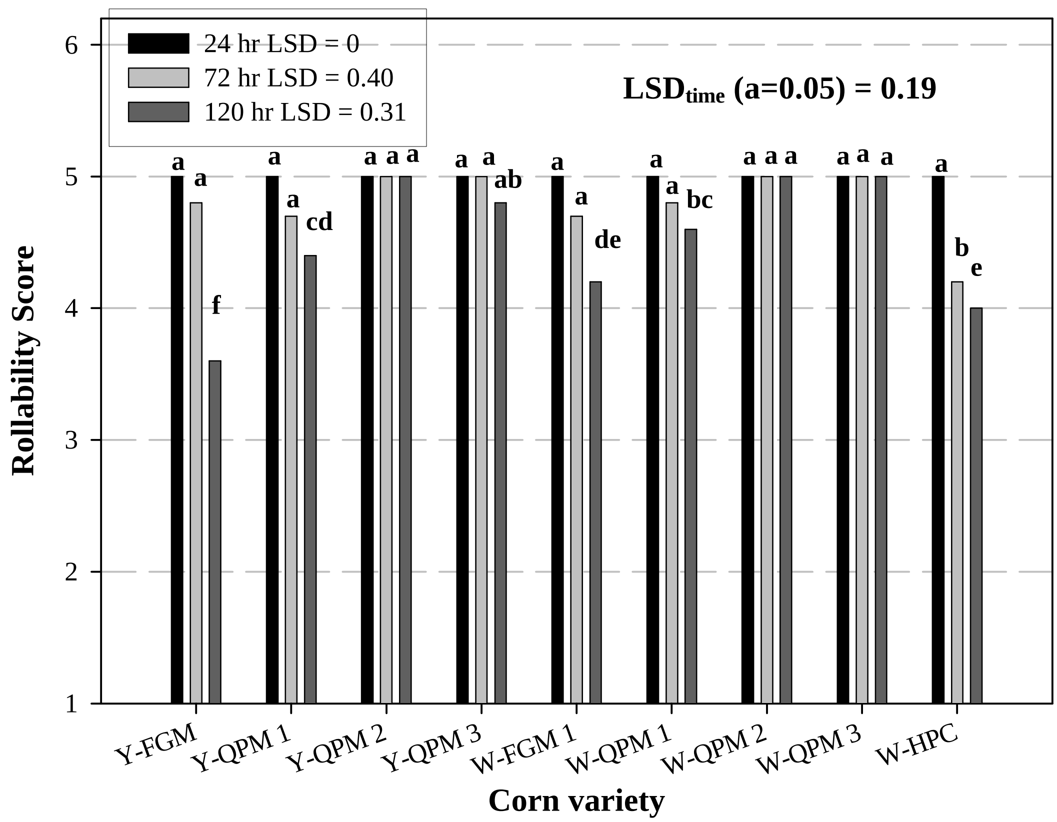

Fig. 16. Effect of storage time (24, 72 and 120 hr) in tortilla rollability. W= white; Y= yellow; FGM= food grade maize; QPM= quality protein maize; HPC= high protein corn. Columns with the same color and letter are not significantly different at a 0.05 level. LSD_{time}= 0.19

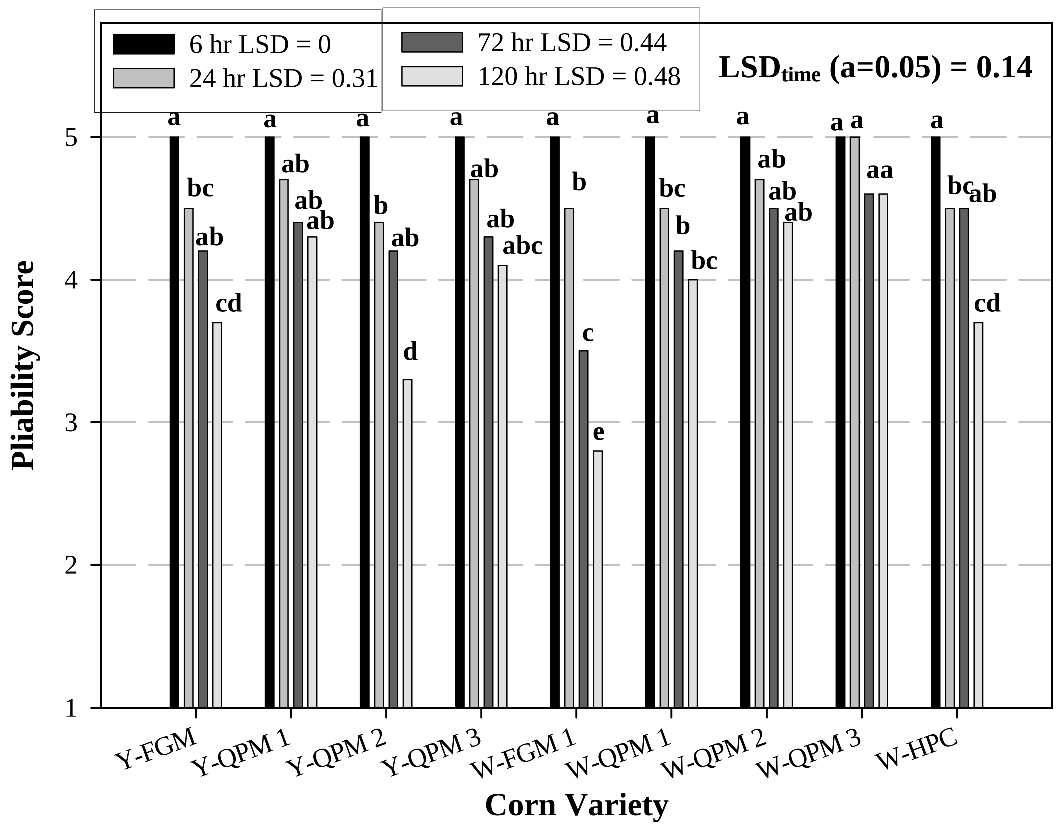

Fig. 17. Effect of storage time (24, 72 and 120 hr) in tortilla pliability. W= white; Y= yellow; FGM= food grade maize; QPM= quality protein maize; HPC= high protein corn. Columns with the same color and letter are not significantly different at a 0.05 level. LSD_{time}= 0.14.

influenced tortilla texture, slowing starch recristalization. The greater protein content in QPM tortillas might have influenced tortilla rollability and pliability. Vittadini and Vodovots (2003) found adding soy to baked products influenced textural properties; it increased moisture content and slowed amylopectin recristalization. Ryan et al. (2002) suggested that soy fractions in bread interacted with starch, thus interfering with the starch recristalization process during storage. Vasal (2001) reported greater glutelin content in QPM varieties. In this study protein fraction was not studied but QPM kernels had greater lysine content; therefore it can be implied that the glutelin content was also greater compared to FGM and might have also contributed to the increase in rollability and pliability.

Results from the evaluation of 1-D extensibility are shown in Figures 18-21 and in Appendix D. The force (N) required to break the tortilla increased and the rupture distance (mm) decreased through storage time, as tortillas were harder and more brittle. Greater changes in rupture force and rupture distance occurred during the first 24 hr.

Tortillas from HPC required less rupture force through storage time compared to QPM and FGM and had similar rupture distance to FGM and QPM (Fig. 20, Fig. 21 and Appendix D). Similar results were reported by Yeggy (2000), HPC tortillas had less rupture force and rupture distance during storage time compared to FGM tortillas. It is likely that the decreased protein content in HPC decreased the force required to break the HPC tortilla. Most QPMs tortillas had greater rupture force and greater rupture distance through storage time compared to FGM and HPC (Appendix D). Sproule (1985) reported QPM tortillas to be perceived by a test panel more rubbery than FGM tortillas. This could be related to the greater rupture force and rupture distance in most of QPM tortillas found during this experiment. The use of extensibility can detect smaller difference between samples during the first 24 hr of storage compared to pliability and rollability. On the other hand at 120 hr of storage, the superior shelf stability of tortillas from QPM compared to FGM and HPC was not

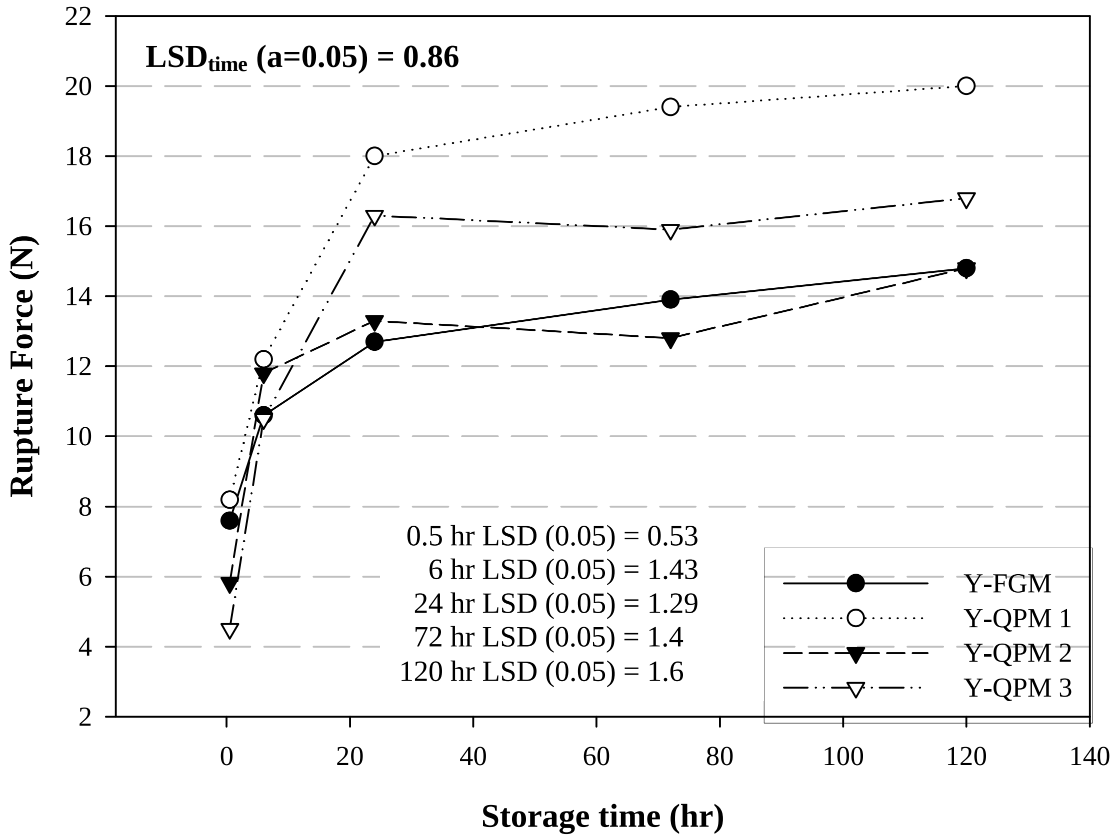

Fig. 18. Effect of storage time on rupture force of tortillas stored for up to 120 hr. Y= yellow; FGM= food grade maize; QPM= quality protein maize. Values are means of four replicates.

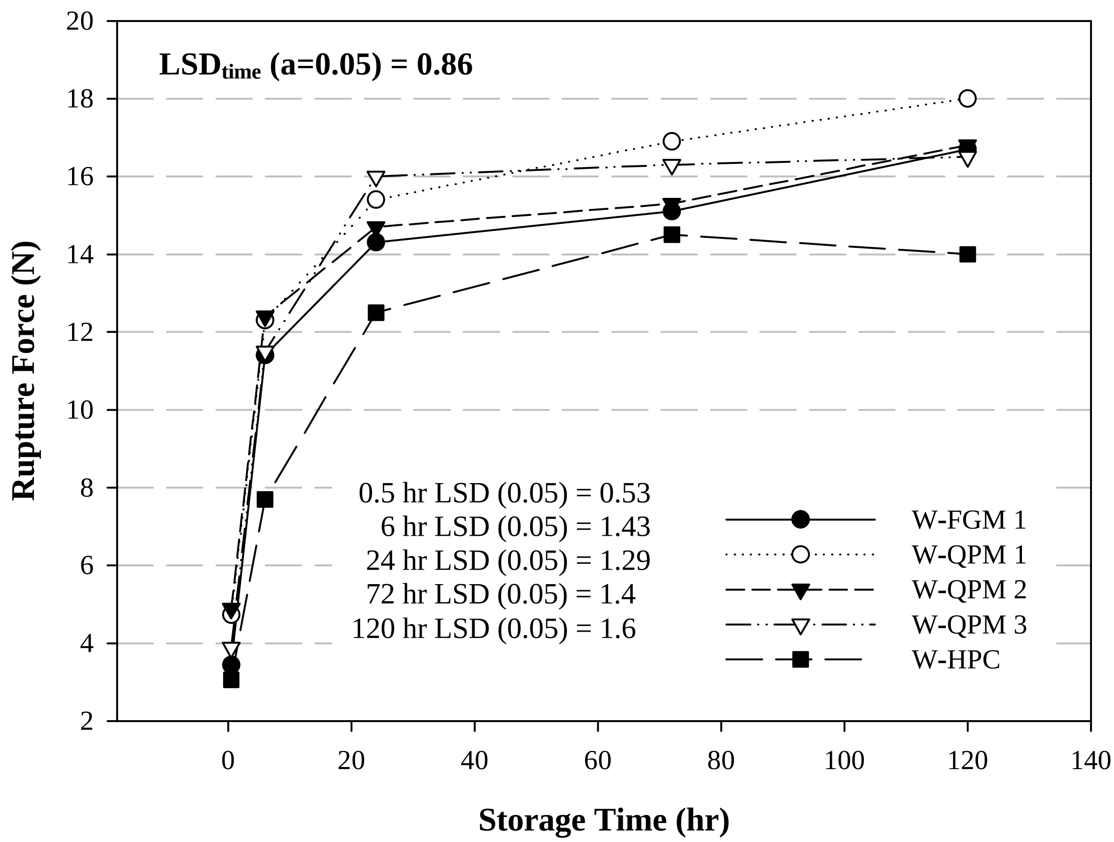

Fig. 19. Effect of storage time on rupture force of tortillas stored for up to 120 hr. W= white; Y= yellow; FGM= food grade maize; QPM= quality protein maize; HPC= high protein corn. Values are means of four replicates.

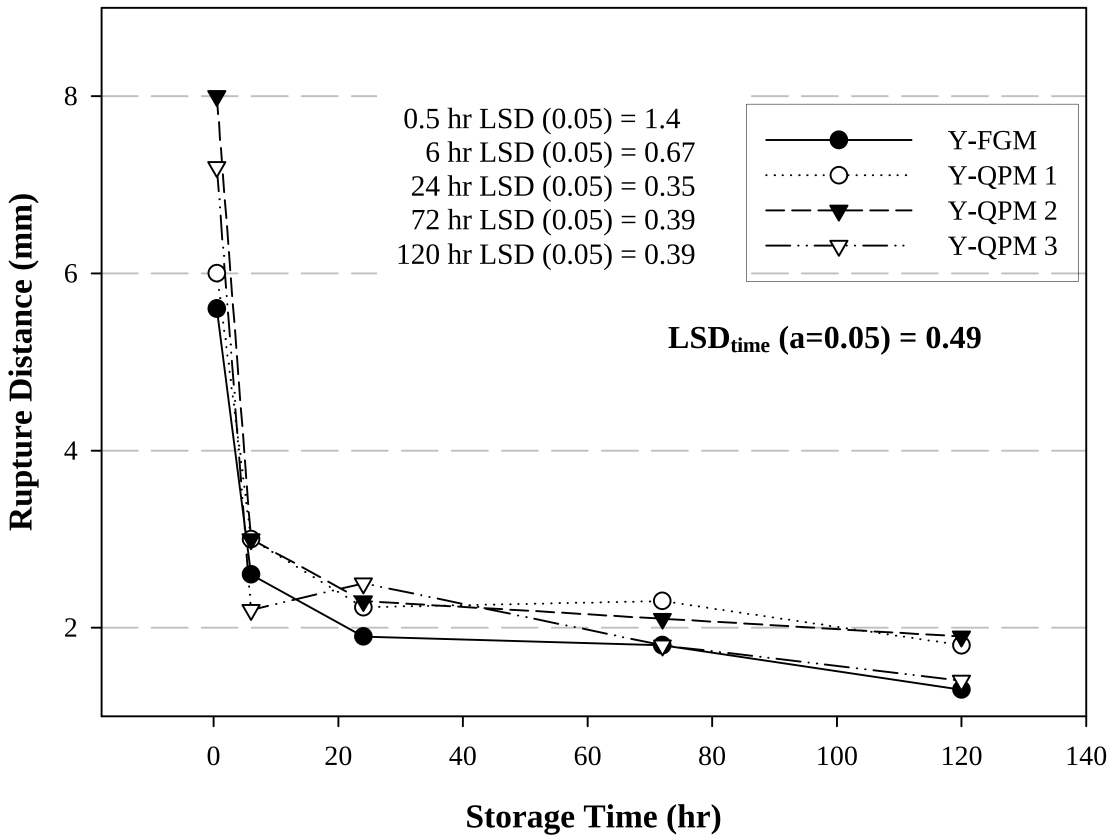

Fig. 20. Effect of storage time on rupture distance of tortillas stored for up to 120 hr. Y= yellow; FGM= food grade maize; QPM= quality protein maize. Values are means of four replicates.

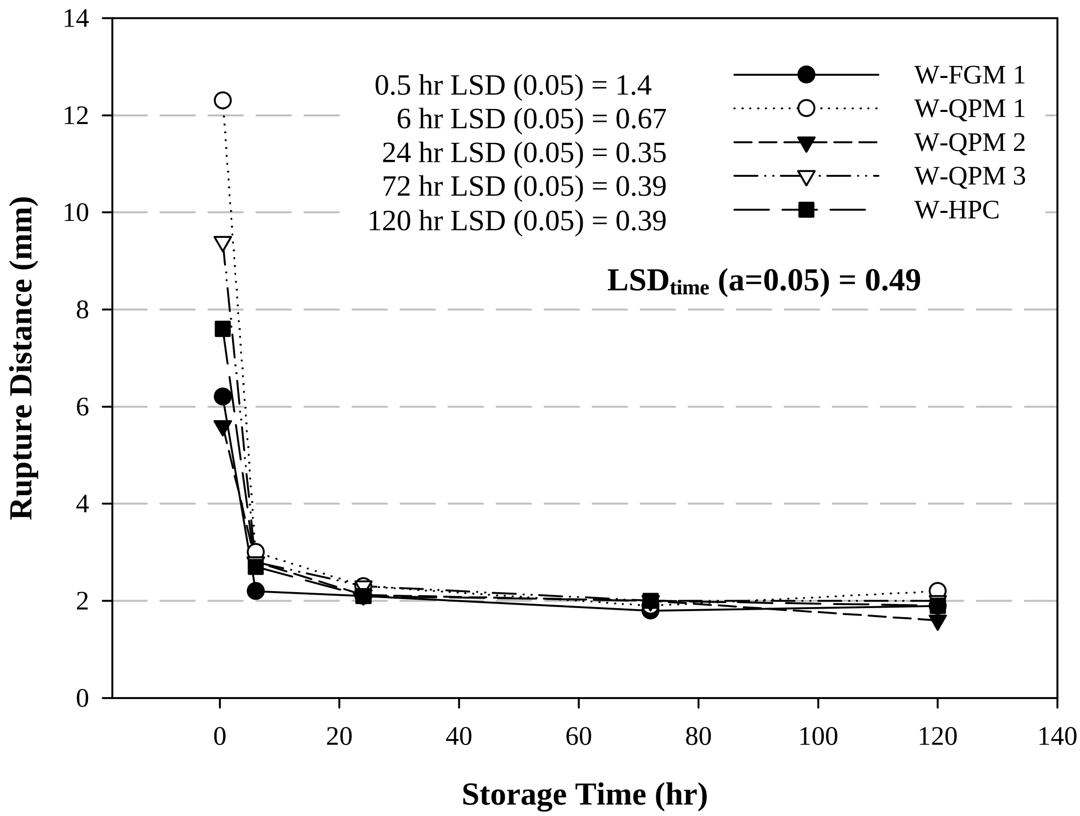

Fig. 21. Effect of storage time on rupture distance of tortillas stored for up to 120 hr. W= white; Y= yellow; FGM= food grade maize; QPM= quality protein maize; HPC= high protein corn. Values are means of four replicates.

as evident analyzing the extensibility compared to the results from rollability and pliability.

Conclusion

QPM, FGM and HPC grains were processed successfully into nixtamal, masa and tortilla. During alkaline cooking, HPC absorbed water faster than QPM and FGM. HPC required shorter cooking time to obtain 50% moisture compared to FGM and most QPMs. White QPM required shorter cooking time had less dry matter losses at the optimum cooking time compared to FGM. Yellow QPM required longer cooking time than FGM but also had less dry matter losses. Therefore using HPC or white QPM during nixtamalization could be beneficial to tortilla producers decreasing energy costs. The use of QPM during alkaline cooking could also decrease sewage costs and grain losses.

All corn varieties had excellent pericarp removal at the optimum cooking time. Nixtamal from all corn varieties was processed into masa suitable for tortilla production, without any change in the process except for Y-QPM 1 that required less water during grinding. Tortillas from QPM had better pliability and rollability after 72 hr compared to FGM and HPC, therefore the use of QPM in tortilla production could increase shelf stability. HPC tortilla required lower rupture force through storage time, therefore HPC has the potential to produce a softer tortilla but further research is needed.

The use of QPM for tortilla production may reduce energy and sewage cost, and produce a tortilla with extend shelf stability and improve nutritional value.

CHAPTER VII

ELABORATION AND EVALUATION OF A DIRECT EXPANDED EXTRUDED SNACK FROM DECORTICATED AND NON-DECORTICATED GRAIN: RESULTS AND DISCUSION

The objective of this experiment was to evaluate and compare direct expanded extruded snacks from decorticated and non-decorticated quality protein maize (QPM), high protein corn (HPC) and food grade maize (FGM). A short scale milling system was used to produce corn meal (Fig. 22). Samples were decorticated 10% to remove part of the pericarp and germ. To remove the big chunks of germ, particles smaller than US standard sieve No. 5 (4 mm) were eliminated. Decorticated samples and non-decorticated samples were hammer-milled through a No. 10 sieve (2 mm). To achieve different particle size, samples were sifted through US standard sieves No. 20 (850 µm) and No. 40 (425 µm). Samples above sieve No. 20 (850 µm) were called coarse, between No. 20 (850 µm) and over No. 40 (425 µm) were called medium, and samples that passed through No. 40 (425 µm) sieve were discarded (≈25%). Corn meal description is shown in Table XIX. Samples were processed in a single-screw, short barrel, high friction, and high shear extruder.

TABLE XIX
Description of Corn Meal Used for Extrusion

SAMPLE	Non-decorticated		10% decorticated	
	Coarse[a]	Meal[b]	Coarse	Meal
Quality protein maize (QPM)	QPM W C	QPM W M	QPM 10 C	QPM 10 M
High protein corn (HPM)	HPM W C	HPM W M	HPM 10 C	HPM 10 M
Food grade maize (FGM)	FGM W C	FGM W M	FGM 10 C	FGM 10 M

[a] Meal that passed through No. 10 US sieve and over No. 20 (850 µm) sieve.
[b] Meal that passed through No. 20 (850 µm) US sieve and over No. 40 (425 µm) sieve.

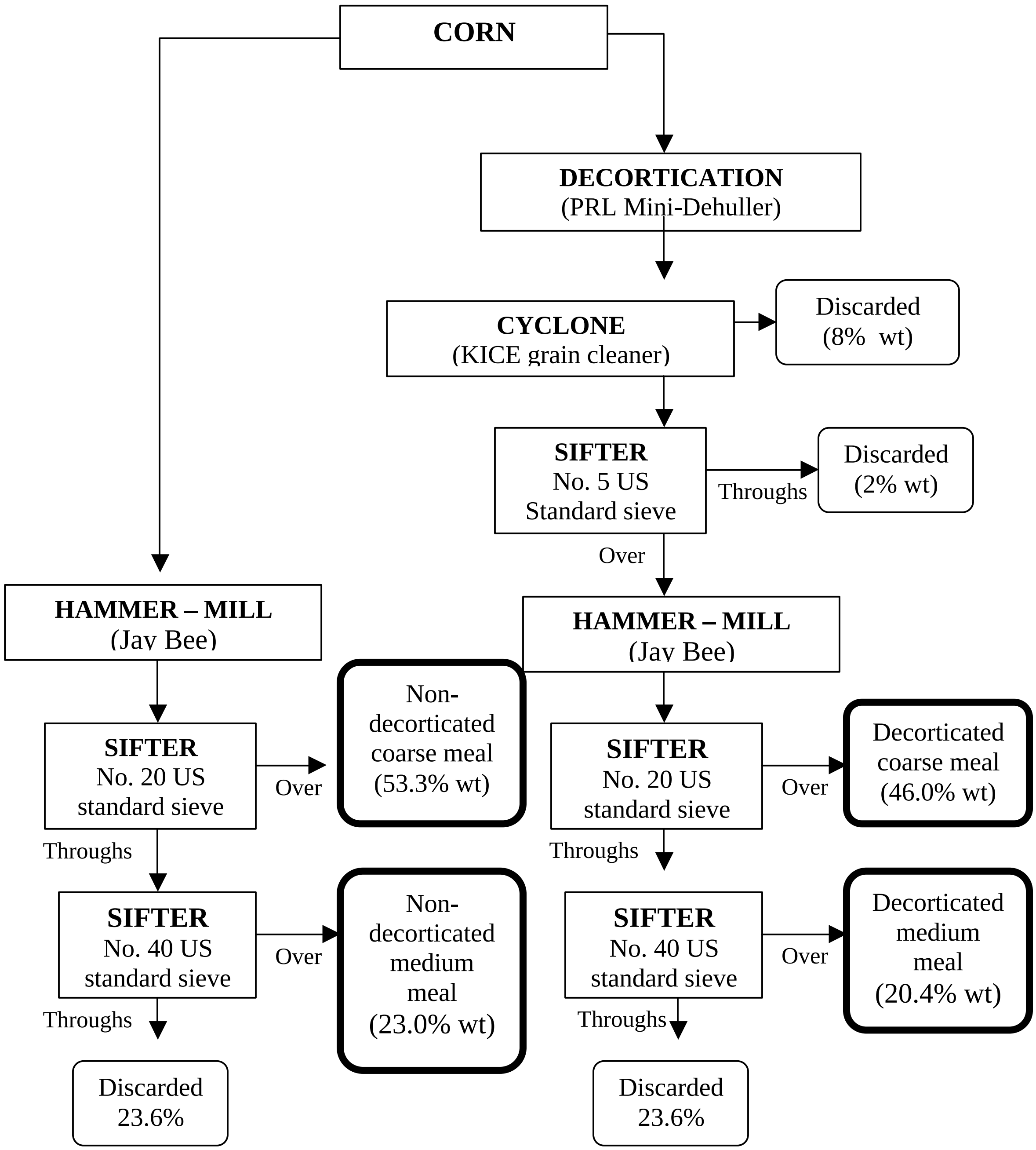

Fig. 22. Flow chart of corn meal production using a short scale milling system. The final products (treatments) and the mean yields are shown in the squares with thicker line.

Extrusion was performed holding knife speed at 25, RPM at 300 and corn meal moisture of 13-14%. Feed rate and amperage were recorded during processing and specific mechanical energy (SME) was calculated. Extrudates were baked at 115°C for 15 min in a forced air oven, equilibrated for 5 min, vacuum packed in metalized bags, and stored at room temperature. Extrudates were analyzed for color, diameter, length, apparent volume, bulk density, radial expansion, force required to break the extrudate, and number of peaks as described in Chapter III.

Corn meal fraction yield

Corn meal yields are shown in Table XX, and Fig. 23. The three corn varieties produced more coarse particle size meal than medium and particle size meal. Yield of coarse particle size meal was between 50.7 and 54.3 % (Appendix B). QPM produced more coarse meal compared to FGM. Wu (1992) reported that QPM yields total grits and prime products comparable to FGM, but in this experiment QPM yield was greater.

Non-decorticated samples produced more coarse particle size meal than decorticated samples (Table XX). Pericarp kept the corneous endosperm together thus increasing coarse particle size yield, additionally; decortication may have caused fissures that weakened the kernel. Kernel density was positively correlated with coarse particles size yield (Fig. 24).

Medium meal yield was not affected by decortication (Table XX). Decorticated samples had more fine particle size meal than non-decorticated; yield was inversely related to grain density (Fig. 25). For this reason a higher density corn is preferred for corn meal production. However, meals hard (flint) kernels require additional time to hydrate in the preconditioner when extruding (Rooney and Suhendro 2001).

TABLE XX
Yield of Corn Meal Fractions Using a Short Flow Milling [a]

SAMPLE[f]	Coarse[c]	Medium[d]	Fine[e]
	< No. 10 > No. 20	< No. 20 >No.40	<No.40
Corn varieties $\bar{X}$	**49.68**	**21.7**	**23.6**
FGM $\bar{X}$	49.0 b	22.3 b	24.8 a
QPM $\bar{X}$	50.5 a	21.2 a	22.3 b
HPC $\bar{X}$	49.5 ab	21.7 ab	23.8 a
LSD[b] $_{\text{corn variety}}$	**1.41**	**0.72**	**1.10**
Decorticated samples $\bar{X}$	46.0 b	20.4 b	23.6 a
Non decorticated samples $\bar{X}$	53.3 a	23.0 a	23.6 a
LSD $_{\text{decortication level}}$	**1.15**	**0.59**	**0.93**

[a] Yield is based on initial kernel weight. Means in the same column (within corn variety and decortication level) followed by the same letter are not significantly different at 0.05 level. FGM = Food grade maize; QPM = Quality protein maize; HPC = High protein corn.
[b] LSD = Least significant difference for mean separation.
[c] Meal through No. 10 (2 mm) US sieve and over No. 20 (850 µm) US sieve.
[d] Meal through No. 20 (850 µm) US sieve and over No. 40 (425 µm) US sieve.
[e] Meal through No. 40 (425 µm) US sieve. This fraction was discarded.
[f] The treatments for every corn variety are shown in Appendix E.

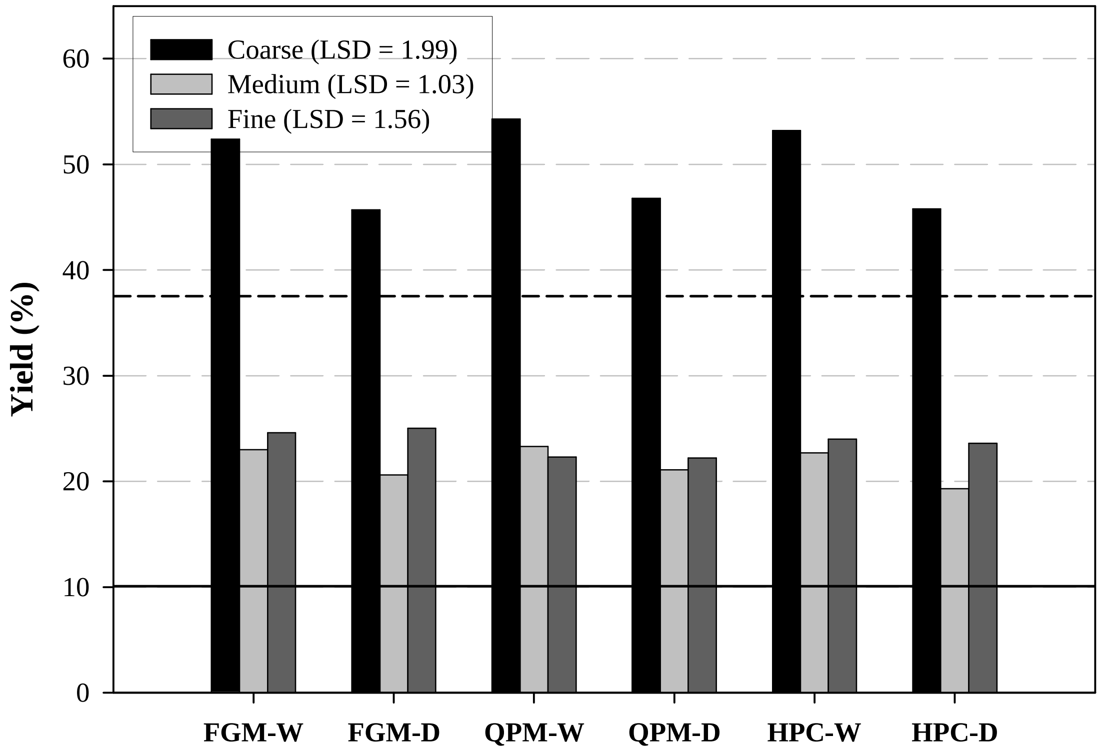

Fig. 23. Corn meal yield from 10% decorticated (D) and non- decorticated (W) food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC). Column with the same color and letter are not significantly different at a 0.05 level. Doted line = 38% Yield for coarse plus regular grits (through No. 10 sieve and over No. 28 sieve); Solid line = 10% yield for corn meal (through No. 28 sieve and over No. 100 sieve) from a commercial dry milling using a modern tempering-degermination process (Rooney and Suhendro 2001).

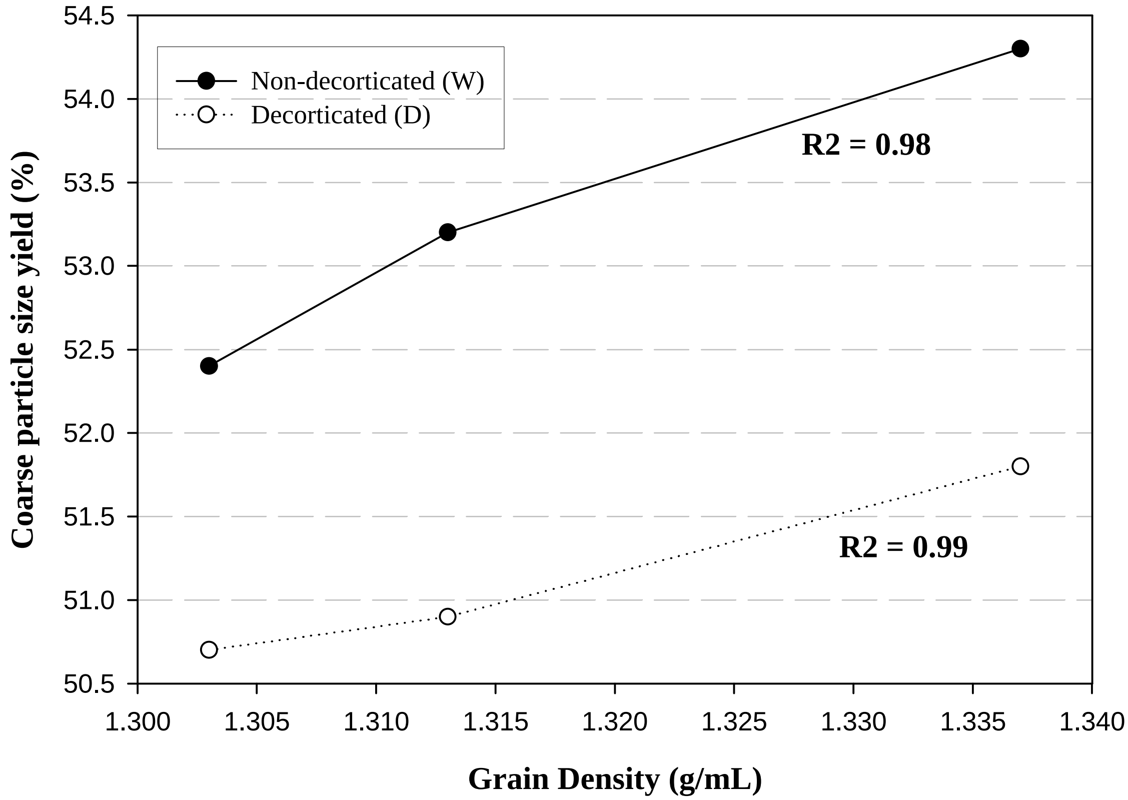

Fig. 24. Effect of kernel density on yield of coarse particle size meal from decorticated and non-decorticated corn.

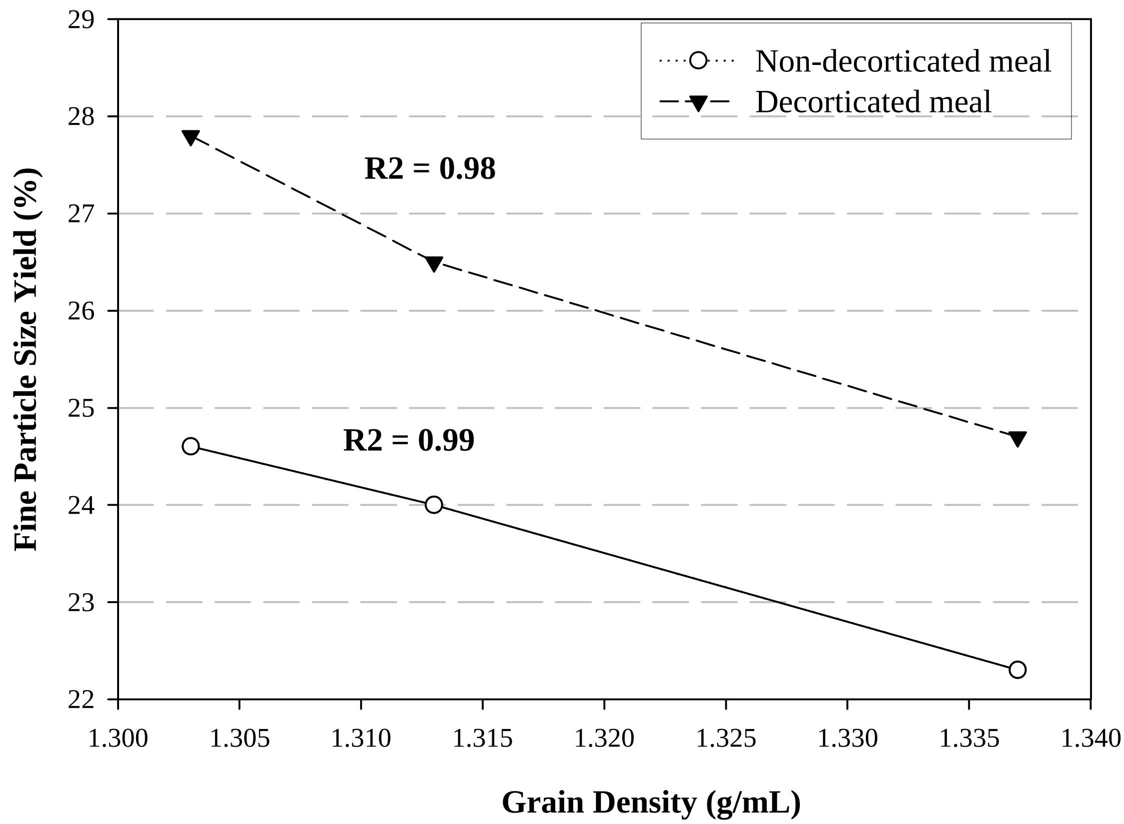

Fig. 25. Effect of kernel density on yield of fine particle size meal from decorticated and non-decorticated corn.

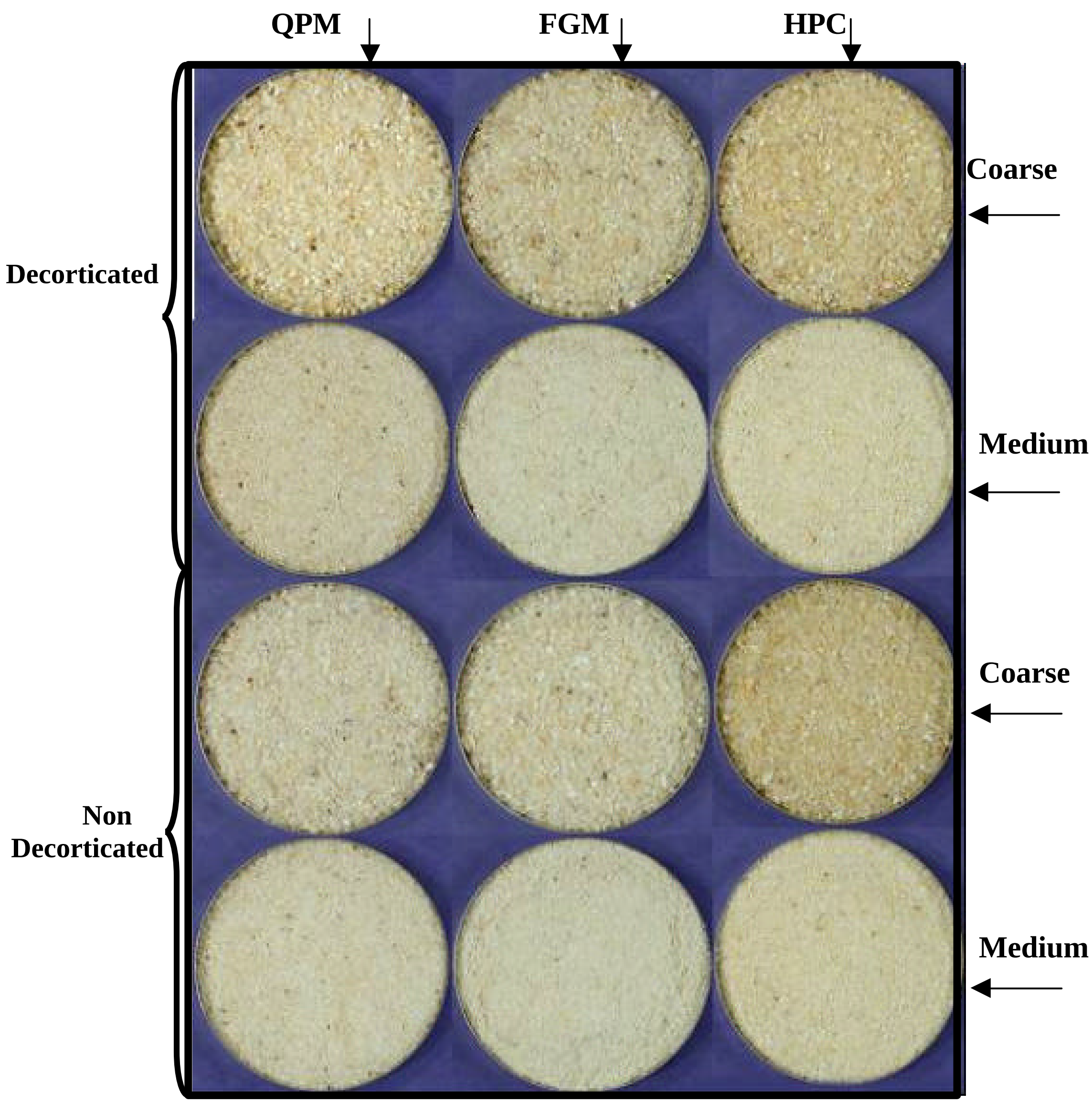

Fig. 26. Corn meal from decorticated and non-decorticated grain, coarse and medium particle size from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC).

TABLE XXI
Color (L*, a* and b*) of Corn Meal from Decorticated and Non-decorticated, Coarse and Medium Particle Size Meal Made From Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC) [a]

SAMPLE[d]	Color		
	L*	a*	b*
Corn varieties	**79.4**	**-0.55**	**15.4**
FGM	79.7 b	-0.74 b	12.9 c
QPM	78.4 c	-0.42 a	15.2 b
HPC	80.3 a	-0.32 a	18.1 a
LSD[b] corn variety	**0.49**	**0.12**	**0.26**
Decorticated samples	79.9 a	-0.74 a	14.9 a
Non decorticated samples	79.0 b	-0.36 b	15.9 b
LSD decortication level	**0.40**	**0.10**	**0.21**
Coarse particle size	77.15 b	-0.15 a	16.7 a
Medium particle size	81.75 a	-0.96 b	14.1 b
LSD particle size	**0.40**	**0.10**	**0.21**

[a] Means in the same column (within corn variety, decortication level and particle size) followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue).
[d] Treatments for every corn variety are shown in Appendix E.

Corn meal color

Objective measurement of the corn meal color is shown in (Table XXII and Appendix E). Pictures of the corn meal are shown in figure 26. The range of L^* (lightness) values for the corn meal were between 75.2 and 83.9. The higher the value, the lighter the corn meal. Within the same corn variety, decorticated samples were lighter ($P < 0.05$) than non-decorticated. Pigments responsible for color are in the pericarp, aleurone layer, endosperm, and scutellum and are affected by pericarp thickness and cob color (Floyd et al. 1995). Pericarp was removed during decortication thus affecting color and increasing lightness. This agrees with Acosta – Sanchez (2003), who reported that lightness increased as decortication of sorghum increased. Medium particle size was lighter ($P < 0.05$) and less yellow (lower b* value) than coarse particle size. Medium particle size composition is high in floury endosperm, which is lighter than corneous endosperm. For all treatments, meal from HPC was more yellow (higher b* value) followed by QPM and FGM (Appendix E). The color of the corn meal will affect the final extrudate color. Most of the commercial corn meal comes from yellow corn, while in this experiment white corn was used.

Corn meal composition

Corn meal composition is shown in Table XXIII and Appendix E. FGM meal had greater moisture and protein content and less fat content than QPM and HPC (Fig. 27 and Fig. 29). Protein content was more affected by particle size than and decortication. Medium particle size had greater ($P < 0.05$) protein content compared to coarse particle size. This could be caused by greater germ content in the medium particle size thus increasing protein content.

Concerning fiber content, there was no significant difference between FGM and QPM (Table XXIII and Fig. 28). Within the same corn variety, decorticated meal had significantly ($P < 0.05$) less fiber than non-decorticated meal. The decortication process decreased effectively the pericarp content.

Regarding fat content, values ranged between 2.7 and 4.6% (Table XXIII and

TABLE XXII
Corn Meal Composition from Decorticated and Non-decorticated Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC)[a]

SAMPLE[a]	Moisture (%)	Protein[c e] (%)	Fiber[e] (%)	Fat[e] (%)
Corn varieties	**12.9**	**11.43**	**1.81**	**3.44**
FGM	13.4 a	12.0 a	1.75 b	1.17 c
QPM	12.5 c	11.6 b	1.76 b	3.73 a
HPC	12.7 b	10.7 c	1.94 a	3.45 b
LSD[b] corn variety	**0.16**	**0.11**	**0.08**	**0.14**
Decorticated	13.0 a	11.4 b	1.26 b	3.38 b
Non-decorticated	12.8 b	11.5 a	2.37 a	3.51 a
LSD decortication level	**0.14**	**0.08**	**0.072**	**0.11**
Coarse particle size	13.4 a	11.1 a	1.85 a	2.83 b
Medium particle size	12.3 b	11.8 b	1.79 a	4.06 a
LSD particle size	**0.14**	**0.9**	**0.72**	**0.11**

[a] Means in the same column (within corn variety, decortication level and particle size) followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] % of protein=N x 6.25
[d] Acid digest fiber.
[e] Expressed on dry weight basis.

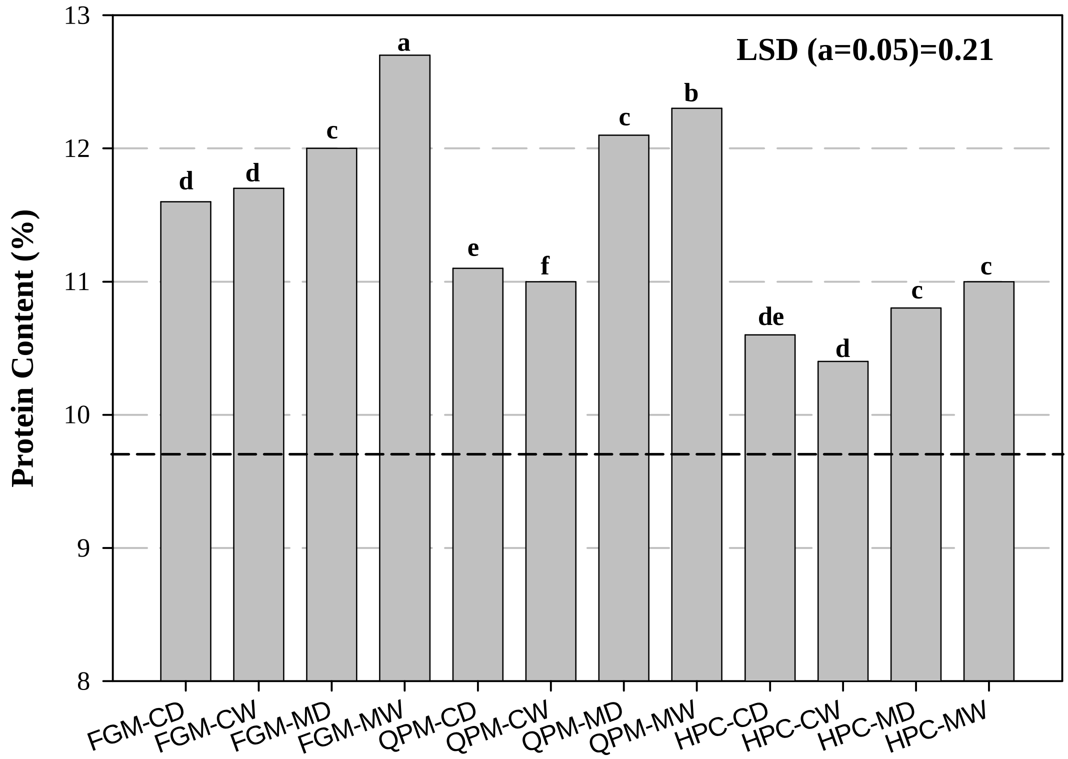

Fig. 27. Corn meal protein content from decorticated (D) and non-decorticated (W), medium particle size (M) and coarse particle size (C) from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC). Expressed on dry weight basis. Protein (%) = N x 6.25. Columns with the same letter are not significantly different at a 0.05 level. Dotted line = 8.4% protein content in commercial corn meal from a degermination process (Rooney and Suhendro 2001).

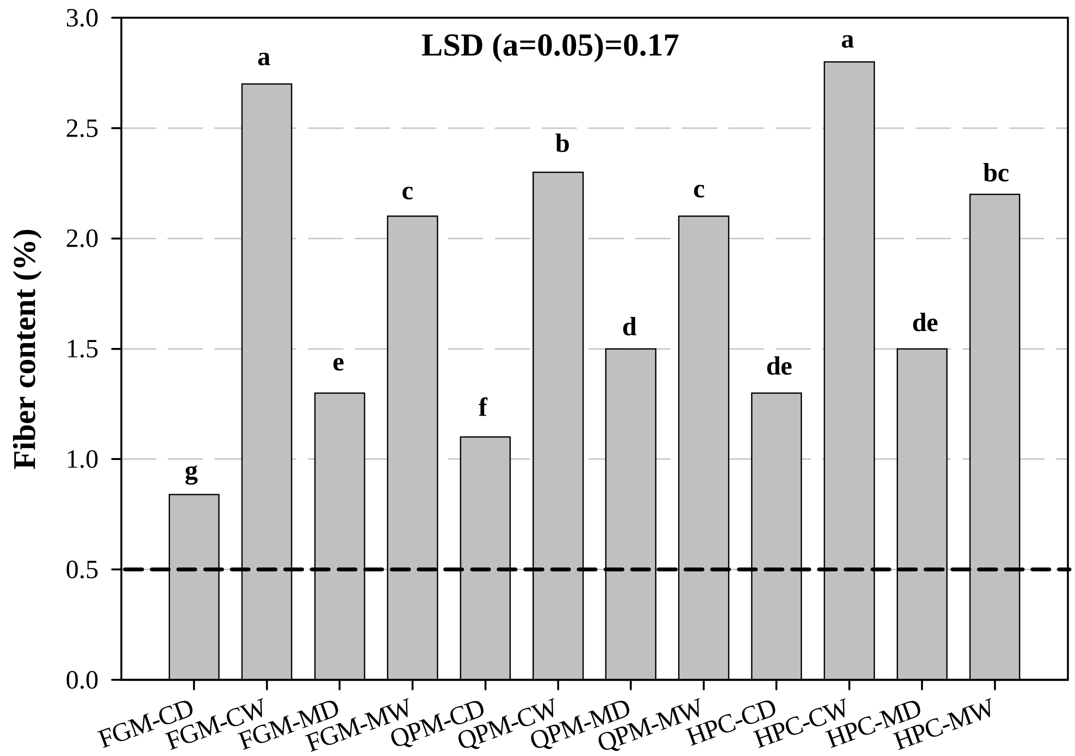

Fig. 28. Corn meal fiber content from decorticated (D) and non-decorticated (W), medium particle size (M) and coarse particle size (C) from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC). Expressed on dry weight basis. Columns with the same letter are not significantly different at a 0.05 level. Dotted line = 0.5% fiber content in commercial corn meal from a degermination process (Rooney and Suhendro 2001).

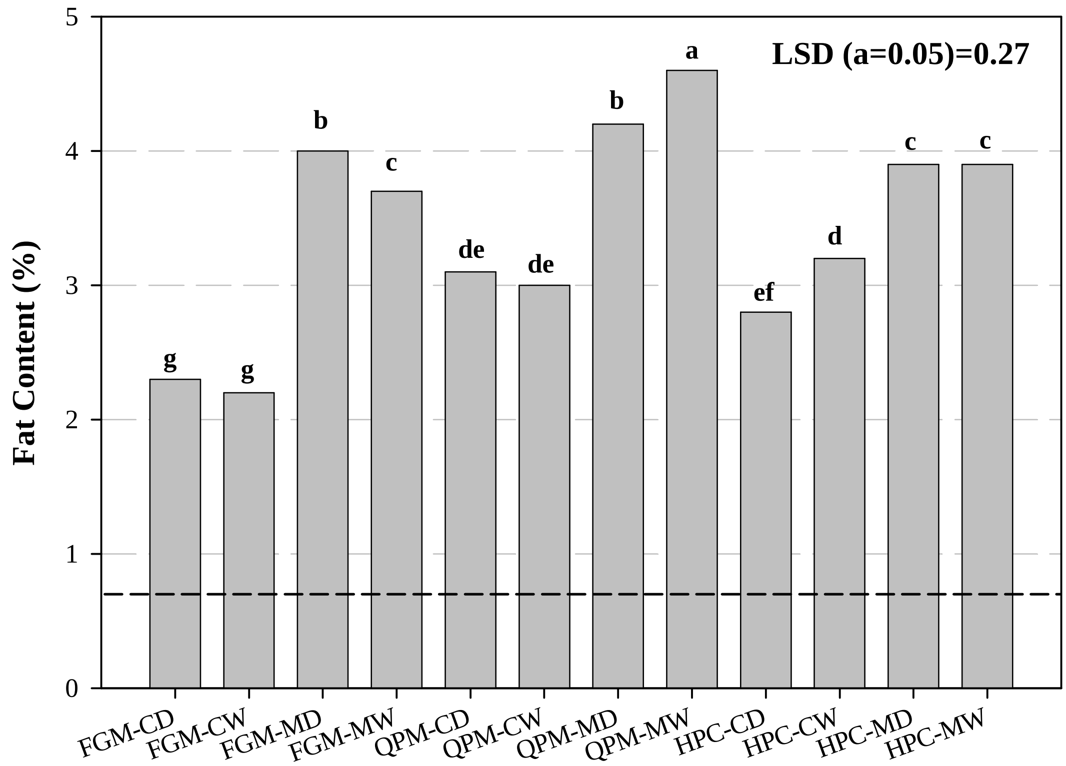

Fig. 29. Corn meal fat content from decorticated (D) and non-decorticated (W), medium particle size (M) and coarse particle size (C) from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC). Expressed on dry weight basis. Columns with the same letter are not significantly different at a 0.05 level. Dotted line = 0.7% fat content in commercial corn meal from a degermination process (Rooney and Suhendro 2001).

Appendix E). FGM had 3.18 times less fat than QPM and 2.94 times less fat than HPC, therefore germ from QPM and HPC was less removed during dry milling. Within the same corn variety, medium particle size had greater lipid content than coarse particle size, probably due to greater germ content in the medium particle size meal, also finer particles tend to absorb fat easier than coarser particles (Desrumaux, et al. 1999). Commercial corn grits and corn meal have oil content of 0.8 and 1.1% respectively (Rooney and Suhendro 2001).

Corn meal amino acid composition

The amino acid composition of QPM and FGM was affected by decortication, milling and particle size (Table XXIV). The decorticated QPM coarse meal had 72% more lysine and 38% more tryptophan than decorticated FGM coarse meal (Fig. 30). From chapter IV, QPM raw grain had 45% more lysine and 38% more tryptophan than FGM, therefore decortication decreased lysine content more in FGM than in QPM; tryptophan content was not affected. This could be caused by a better germ removal during decortication in FGM than in QPM. Non-decorticated QPM coarse meal had 45% more lysine and 41% more tryptophan compared to non-decorticated FGM coarse meal.

Decorticated and non-decorticated QPM meal had more of the amino acids lysine (57%), tryptophan (40%), arginine (59%), histidine (43%), cystein (46%) and aspartic acid (12%); and had less of the amino acids leucine (35%), alanine (24%) and glutamic acid (14%) than FGM. QPM meals had higher protein quality compared to FGM meals.

Processing conditions

QPM required more ($P < 0.05$) energy (Amps) for extrusion and extruded faster than FGM and HPC (Table XXV and Fig. 31). Energy consumption in the extruder increased with increasing feed rate, and the specific mechanical energy (SME) decreased, this agrees with Ilo et al. (1996).

TABLE XXIII
Amino Acid Content of Corn Meal from Decorticated and Non-decorticated, Coarse Particle Size Meal From Food Grade Maize (FGM) and Quality Protein Maize (QPM).

Amino Acid[a]	% Relative Std. Dev.[f]	FGM-CW[b]	FGM-CD[c]	QPM-CW[d]	QPM-CD[e]
		(mg/ 100g protein)			
Hydroxyproline	1.95	0.28	0.19	0.20	0.19
Aspartic Acid	1.06	5.87	5.65	6.39	6.54
Threonine[a]	0.74	3.22	3.07	3.50	3.41
Serine	1.4	3.88	3.93	3.80	3.79
Glutamic Acid	1.01	18.73	19.64	16.48	16.40
Proline	1.67	8.70	9.00	8.99	8.91
Glycine	0.76	3.60	3.26	4.60	4.64
Alanine	0.68	7.47	7.57	5.69	5.69
Cysteine	0.64	2.27	2.39	3.20	3.60
Valine[a]	0.53	4.73	4.69	5.29	5.21
Methionine[a]	0.99	2.18	2.30	1.80	1.90
Isoleucine[a]	0.48	3.41	3.35	2.90	2.84
Leucine[a]	0.49	12.39	13.03	8.29	8.15
Tyrosine	0.44	2.93	2.78	2.60	2.37
Phenyalanine[a]	0.55	4.73	4.79	3.80	3.70
Histidine	0.83	2.84	2.87	4.10	4.08
Lysine[a]	0.7	2.55	2.20	3.70	3.79
Arginine	1.64	4.26	3.93	6.39	6.64
Tryptophan[a]	1.36	0.57	0.48	0.80	0.66

[a] Essential amino acid, which means it can not be synthesized by the human body.
[b] Coarse particle size, non decorticated meal from food grade maize.
[c] Coarse particle size, decorticated meal from food grade maize.
[d] Coarse particle size, non decorticated meal from quality protein maize.
[e] Coarse particle size, decorticated meal from quality protein maize.
[f] % Relative standard deviation of the amino acid standard used.

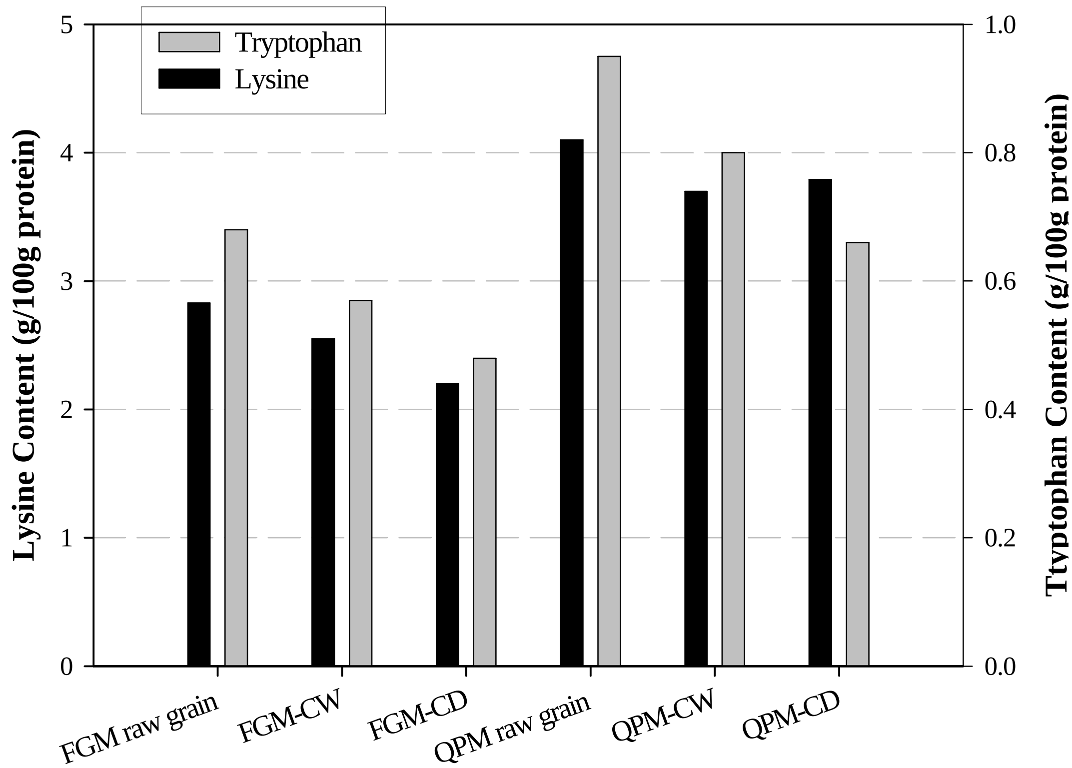

Fig. 30. Effect of corn meal production on lysine and tryptophan content from food grade maize (FGM) and quality protein maize (QPM) raw grain and meal. CW = coarse particle size non-decorticated. CD = coarse particle size decorticated meal.

TABLE XXIV
Energy Consumed, Torque, Feed Rate and Specific Mechanical Energy (SME) During Extrusion of Decorticated and Non-decorticated Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC)[a]

SAMPLE[g]	Energy (Amps)	Feed Rate[c] (g/sec)	SME[d] (kJ/kg)
Corn varieties	**28.8**	**37.3**	**97.4**
FGM	27.9 b	34.6	103 a
QPM	30.4 a	39.5	98 b
HPC	28.2 b	37.9	92 c
LSD[b] corn variety	**0.91**	**---**	**3.7**
Decorticated	29.9 a	38.9	99 a
Non decorticated	27.8 b	35.8	96 a
LSD decortication level	**0.74**	**---**	**3.07**
Coarse particle size	31.1 b	40.24	100 a
Medium particle size	26.6 a	34.42	94 b
LSD particle size	**0.74**	**---**	**3.07**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Only one measurement was taken, therefore there is no LSD.
[d] Specific mechanical energy. SME= (Torque) (screw speed) / Feed rate.
[g] Treatments for every corn variety are shown in appendix E.

Coarse particle size meal required more ($P < 0.05$) energy, more ($P < 0.05$) SME and had a higher feed rate compared to medium particle size meal. Probably the higher lipid content in the medium particle size meal, acted as a lubricant decreasing friction inside the barrel (Fig. 32). Meal from decorticated grain required more energy and had higher feed rate compared to non-decorticated samples. Decorticated meal had less lipids, fiber and protein, thus more starch, increasing viscosity inside the barrel, and increasing energy consumption.

The specific mechanical energy (SME) in this study was between 85 and 105 kJ/kg (Appendix E). FGM required greater SME followed by QPM and HPC. Decortication did not affect SME and the coarse fraction required greater SME than the medium fraction. Gropper et al. (2002) reported that starch gelatinization is strongly affected by SME during extrusion. Mechanical energy catalyzes the gelatinization reaction by rupturing intermolecular hydrogen bonds. The higher the SME the higher the degree of gelatinization during extrusion. Therefore FGM had greater expansion since it had greater SME.

Extrudate physical characteristics

Expansion of the extrudate is due to the sudden vaporization of the water caused by a decrease in pressure (Padmanabhan and Bhattacharya, 1989). It depends on the feed composition, extent of cooking and melt flow in the die (Desrumaux et al. 1998).

Extrudate diameter (mm), length (mm), apparent volume (mm^3), and radial expansion are shown in Table XXVI and Appendix E. FGM extrudates had greater diameter, thus greater radial expansion followed by HPC and QPM. QPM had lower expansion most likely because of the higher lipid content. Lipids act as a lubricant decreasing friction inside the barrel thus decreasing expansion. This agrees with Faubion et al. (1982), who reported that adding lipids reduced expansion in extrudates.

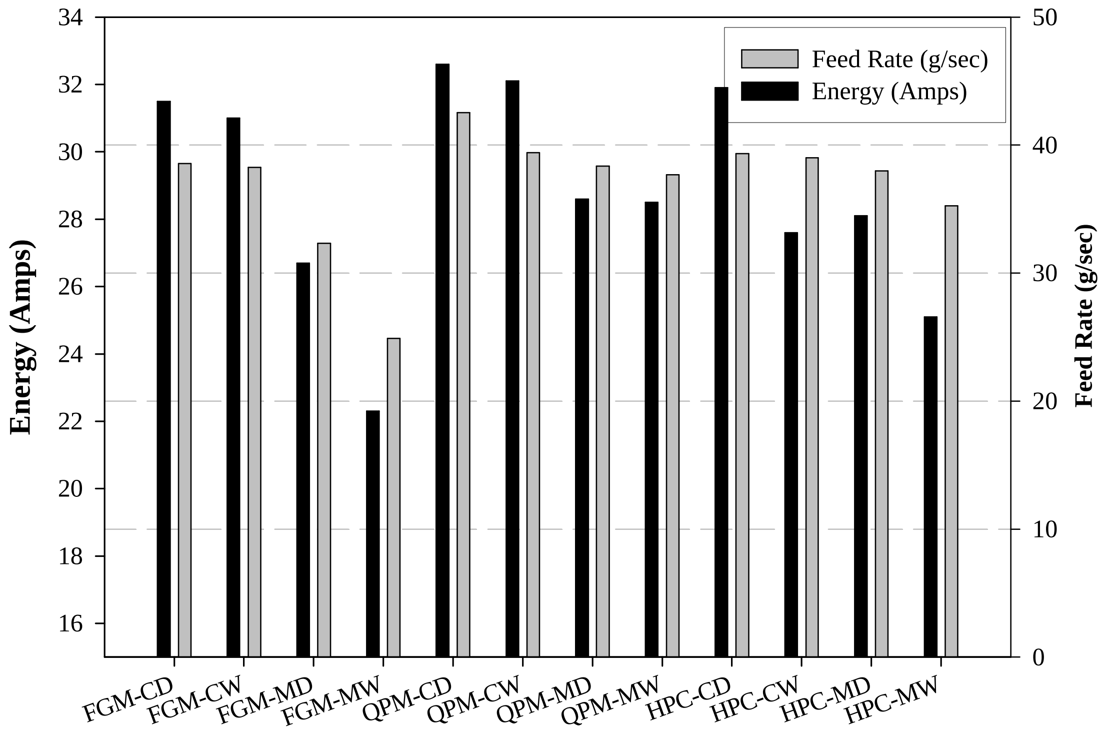

Fig. 31. Energy (Amps) consumed and feed rate (g/sec) during extrusion of corn meal from decorticated (D) and non-decorticated (W), medium particle size (M) and coarse particle size (C) from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC).

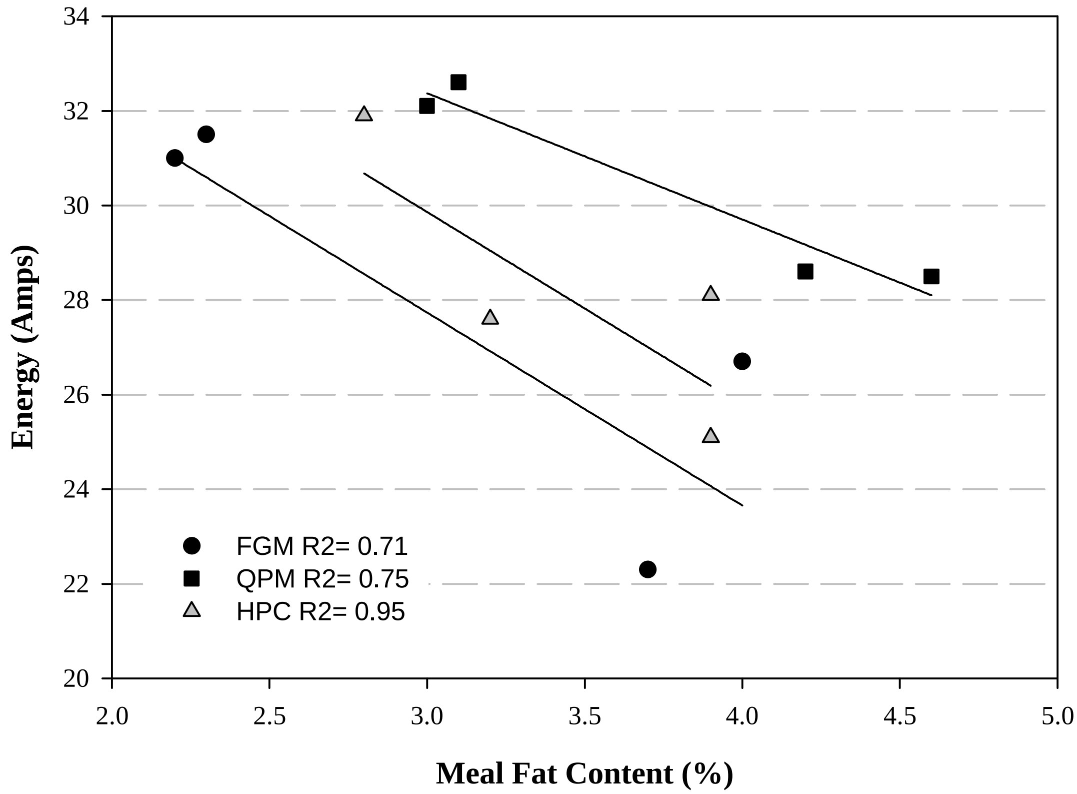

Fig. 32. Effect of fat content on energy (Amps) consumed during extrusion of food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC).

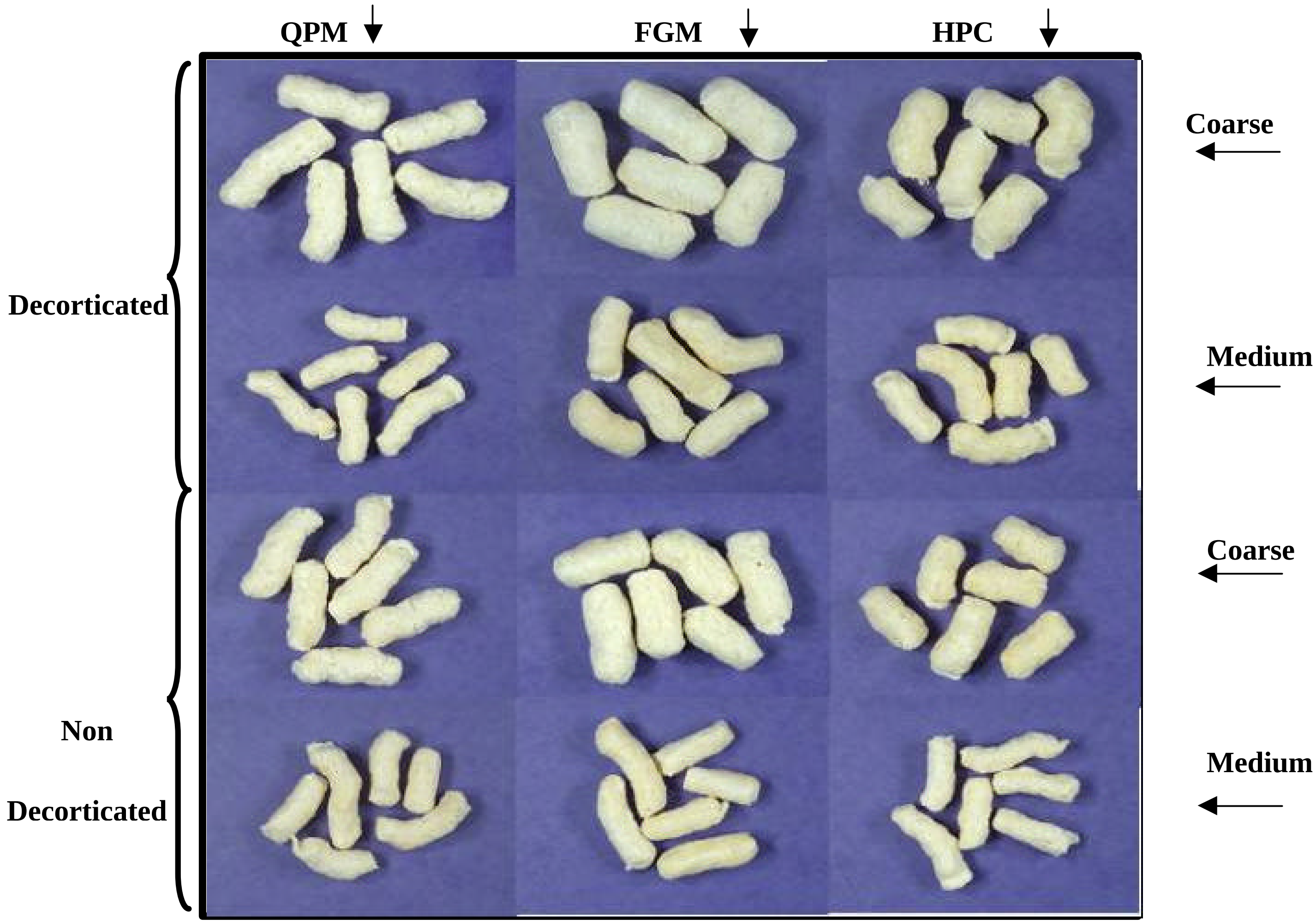

Fig. 33. Picture of the extrudates from coarse and medium particle size meal from decorticated and non-decorticated quality protein maize (QPM), food grade maize (FGM), and high protein corn (HPC).

TABLE XXV
Extrudate Diameter, Length, Apparent Volume and Radial Expansion From Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC)[a]

SAMPLE[e]	Diameter (mm)	Length (mm)	Apparent volume[c] (mm^3)	Radial expansion[d]
Corn varieties	**12.6**	**31.3**	**4052.8**	**3.97**
FGM	14.0 a	35.8 a	14.0 a	4.4 a
QPM	11.2 c	35.5 a	11.2 c	3.6 c
HPC	12.3 b	22.4 b	12.3 b	3.9 b
LSD[b] $_{\text{corn variety}}$	**0.35**	**1.53**	**348**	**0.11**
Decorticated	13.1 a	32.3 a	13.1 a	4.1 a
Non decorticated	12.1 b	30.3 b	12.1 b	3.8 b
LSD $_{\text{decortication level}}$	**0.28**	**1.25**	**284**	**0.09**
Coarse particle size	14.5 a	29.2 a	14.5 a	4.6 a
Medium particle size	10.8 b	33.3 b	10.8 g	3.4 b
LSD $_{\text{particle size}}$	**0.28**	**1.25**	**284**	**0.09**

[a] Means in the same column (within corn variety, decortication level and particle size) followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for means separation.
[c] Apparent volume = π (extrudate diameter / 2)^2 (extrudate length).
[d] Radial expansion = extrudate diameter / die diameter.
[e] Treatments for every corn variety are shown in appendix E.

TABLE XXVI
Bulk Density, Peak Force, Work and Number of Peaks From Extrudates of Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC)[a]

SAMPLE[e]	Bulk density (g/mL)	Peak Peak[c] (g)	Number of peaks[d]
Corn varieties	**0.184**	**2982**	**27.0**
FGM	0.144 c	2261 c	32.2 a
QPM	0.196 b	3273 b	20.9 c
HPC	0.213 a	3412 c	27.7 b
LSD[b] $_{\text{corn variety}}$	**0.0013**	**243**	**2.83**
Decorticated	0.179 b	3051 a	26.9 a
Non decorticated	0.190 a	2914 a	27.0 a
LSD $_{\text{decortication level}}$	**0.001**	**172**	**2.15**
Coarse particle size	0.138 b	2499 b	34.7 a
Medium particle size	0.231 a	3466 a	19.2 b
LSD $_{\text{particle size}}$	**0.001**	**172**	**2.15**

[a] Means in the same column (within corn variety, decortication level and particle size) followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for means separation.
[c] Force required to break the extrudate.
[d] Number of peak force required to break the extrudate.
[e] Treatments for every corn variety are shown in appendix D.

De Muelenaere and Buzzard (1969) extruded degermed corn grits and whole corn meal (with higher lipid content) and found that degermed corn grits had greater expansion capabilities than whole corn. In this experiment extrudate diameter decreased as lipid content increased (Appendix E). FGM extrudate had greatest apparent volume and lower bulk density followed by QPM extrudate and HPC extrudate (Table XXVI). Even though HPC had greater radial expansion than QPM, it had lower longitudinal expansion thus decreasing the apparent volume and increasing the bulk density. Decortication and meal particle size also affected extrudate expansion. Extrudates from coarse particle size had greater diameter, radial expansion and apparent volume whith lower bulk density. Meal from decorticated grain had greater diameter, length, apparent volume and radial expansion and lower bulk density. Therefore coarse particle size meal from decorticated grain produced the best extrudates.

Extrudate peak force (a measure of the extrudate hardness) and number of peaks required to break the extrudates (a measure of crispiness) are shown in Table XXVII and Appendix E. HPC extrudates required greater ($P < 0.05$) force to be broken followed by QPM and FGM (Table XXVII). Peak force values ranged between 1314 g and 4123 g (Appendix D). The increased amylose content (Strissel and Stiefel 2002) in HPC might have increased HPC extrudate hardness. Extrudates from coarse particle size meal required less force to break compared to extrudates from medium particle size meal. FGM extrudates had more peaks followed by HPC and QPM. The number of peaks is related to the product crispiness and the number of air cells retained. A high number of peaks is desired because of higher expansion and decreased bulk density. The number of peaks was negatively related to bulk density (Fig. 34). This correlation was higher for QPM and FGM compared to HPC.

HPC extrudates were the lightest (greater L* value) followed by QPM and FGM extrudates (Table XXVIII and Fig. 33). Decorticated extrudates were lighter than non-decorticated, and extrudates from coarse particle size were lighter than extrudates from medium particle size. Extrudates from HPC were more yellow (greater b* value) than

FGM and QPM. Differences in extrudate color could be minimized by applying colored seasoning

The effect of extrusion on amino acid content is shown in Table XXIX. Most of the amino acid contents remained the same when compared to the meal before extrusion to the extrudate, except valine that increased 10% and tryptophan that increased 48%. Since the amino acid analyses were not done in duplicate, it would be recommended to do further research on the increase of tryptophan during extrusion.

Conclusion

QPM, FGM and HPC were successfully processed into corn meal and direct expanded extrudates using a short scale dry milling system and a single screw extruder. QPM, FGM and HPC produced more coarse particle size meal than medium particle size meal. QPM produced more ($P > 0.05$) coarse meal compared to FGM and similar to HPC. Decortication decreased coarse meal yield. Density was positively related with coarse particle size meal yield and inversely related with fine particle size meal yield.

Meal from the three corn varieties had greater fat, protein and fiber content compared to commercial corn meal. QPM and HPC had similar protein content, both lower than FGM meal. FGM had less fat than QPM and HPC. Fiber content was similar in QPM, FGM and HPC. Decortication decreased fiber content. QPM improved nutritional value was kept or increased during corn meal production. Coarse meal from decorticated and non-decorticated QPM had 72% and 45% more lysine, respectively and 38% and 41% more tryptophan compared to coarse meal from decorticated and non-decorticated FGM. The short-scale milling system used in this experiment could be an excellent option to small health food producers.

QPM extruded faster than FGM and HPC. FGM required higher specific mechanical energy than QPM. Therefore the use of QPM meal could decrease energy costs. Extrudates from FGM had the lowest bulk density followed by QPM and HPC. Extrudates from HPC were the hardest (greatest peak force), followed by QPM and FGM. HPC extrudates had higher radial expansion than QPM extrudates but were shorter, therefore

HPC apparent volume was lower compared to QPM. FGM extrudates had more force peaks followed by HPC and QPM, which means they retained more air cells.

Lysine content in QPM was not affected by extrusion, therefore it is possible to produce a direct expanded snack from QPM with improved nutritional value.

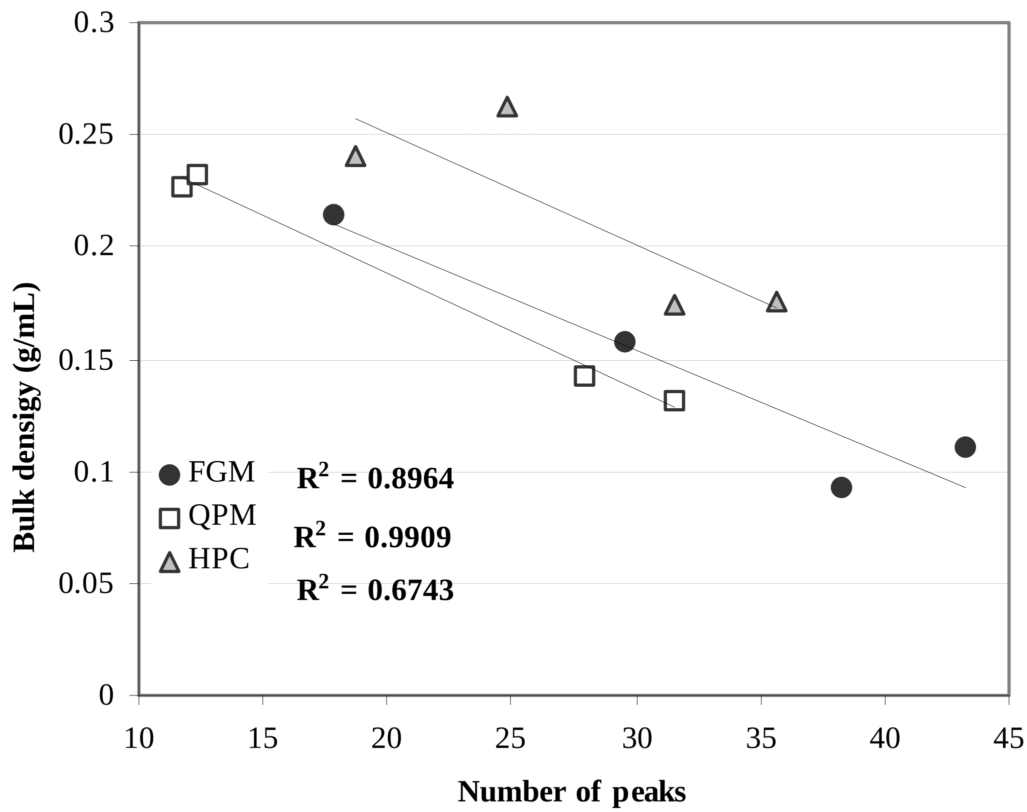

Fig. 34. Relationship between the numbers of force peaks and the extrudate bulk density (g/mL). Extrudates were made from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC).

TABLE XXVII
Extrudate Color From Decorticated and Non-decorticated, Coarse and Medium Particle Size Meal Made From Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC) [a]

SAMPLE[d]	Color		
	L*	a*	b*
Corn varieties	**86.5**	**-1.22**	**15.6**
FGM	86.4 b	-0.96 a	16.0 c
QPM	86.3 c	-1.18 ab	15.3 b
HPC	86.7 a	-1.52 b	16.4 a
LSD[b] $_{\text{corn variety}}$	**0.10**	**0.38**	**0.06**
Decorticated samples	86.9 a	-1.28 a	15.1 b
Non decorticated samples	86.0 b	-1.17 a	16.0 a
LSD $_{\text{decortication level}}$	**0.08**	**0.31**	**0.1**
Coarse particle size	86.5 a	-1.23 a	15.0 b
Medium particle size	86.4 b	-1.22 a	16.2 a
LSD $_{\text{particle size}}$	**0.08**	**0.31**	**0.1**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue).
[d] Treatments for every corn variety are shown in appendix D.

TABLE XXVIII
Effect of Processing (Raw Grain to Extrudate) in Amino Acid Content of QPM.

Amino Acid[d]	% Relative Std. Dev.[e]	W-QPM 3[a] Raw grain mg/ 100g protein	W-QPM 3[a] Meal[b] mg/ 100g protein	W-QPM 3[a] Extrudate[c] mg/ 100g protein
Hydroxyproline	1.95	0.32	0.20	0.00
Aspartic Acid	1.06	6.93	6.39	6.40
Threonine[d]	0.74	3.68	3.50	3.54
Serine	1.4	3.99	3.80	3.74
Glutamic Acid	1.01	16.91	16.48	16.34
Proline	1.67	9.03	8.99	8.86
Glycine	0.76	0.00	4.60	4.63
Alanine	0.68	5.04	5.69	5.81
Cysteine	0.64	5.99	3.20	2.85
Valine[d]	0.53	3.15	5.29	5.71
Methionine[d]	0.99	5.67	1.80	1.67
Isoleucine[d]	0.48	1.79	2.90	3.05
Leucine[d]	0.49	3.05	8.29	8.76
Tyrosine	0.44	8.40	2.60	2.36
Phenyalanine[d]	0.55	2.63	3.80	4.04
Histidine	0.83	3.89	4.10	4.13
Lysine[d]	0.7	4.10	3.70	3.74
Arginine	1.64	7.04	6.39	6.20
Tryptophan[d]	1.36	0.95	0.80	1.18

[a] White QPM from CIMMYT (W-QPM 3).
[b] Coarse particle size meal (>No. 20 (850 µm) US sieve) from non-decorticated W-QPM 3.
[c] Extrudate from coarse particle size meal from non-decorticated W-QPM 3.
[d] Essential amino acid, which means it can not be synthesized by the human body.
[e] % Relative standard deviation of the amino acid standard used.

CHAPTER VIII

SENSORY EVALUATION OF EXTRUDATES: RESULTS AND DISCUSION

The objective of this experiment was to evaluate the organoleptic properties of the extrudates. Thirty untrained panelist from Texas A&M University evaluated the extrudates from quality protein maize (QPM), high protein corn (HPC) and food grade maize (FGM). The extrudates evaluated were made from coarse particle size meal from decorticated and non-decorticated grain. These treatments were selected because they had the best characteristics (Chapter VII). Samples were flavored following a formulation used in a similar product made of whole sorghum (*unpublished* Leal 2002) The formulation is shown in Table XXX. To obtain the same moisture content, all samples were baked before the sensory test. A sample form used by the panelists during the evaluation is shown in Figure 35. Flavored extrudates were evaluated for crispiness and adhesiveness using an intensity scale (1=very easy to 9=very hard). The acceptability of the shape, hardness and flavor was evaluated using a hedonic scale (1=extremely dislike to 9=extremely like) (Camire et al. 1991, Pedrero and Pangborn 1997, Rampersad et al. 2003).

TABLE XXIX
Extrudate Flavoring Formulation

Ingredient	**Slurry**	**Dry flavoring**	**Extrudate**
	(%)	**(%)**	**(%)**
Corn oil	70	0	0
Buffalo wings flavor [a]	20	70	0
Salt	0.5	0.5	0
Acid whey	9.5	30	0
Final product percentage	**35%**	**15%**	**55%**

[a] Buffalo wings McCormick & Co., Inc. Hunt Valley, MD.

INSTRUCTIONS: Please circle the number that best fits your description

SHAPE APPEARANCE: How do you like its shape and size?
1 2 3 4 5 6 7 8 9
Dislike extremely Neither like of dislike Like extremely

HARDNESS How does it feel at the first bite?
1 2 3 4 5 6 7 8 9
Dislike extremely Neither like of dislike Like extremely

CRISPINESS Does it fracture and crumble into small pieces after the first bite?
1 2 3 4 5 6 7 8 9
Very easy Neither easy nor difficult Very difficult

ADHESIVENESS How easy does it remove from the teeth?
1 2 3 4 5 6 7 8 9
Very easy Neither easy nor difficult Very difficult

FLAVOR How do you like the flavor?
1 2 3 4 5 6 7 8 9
Dislike extremely Neither like of dislike Like extremely

Fig. 35. Taste panel form used for each sample during the sensory evaluation.

The panel composition was 52% male and 48% female. Of the thirty panelist, 39% were from United States, 45% Latin, 10% Asian and 6% African. The age distribution of the panel was 65% between 20 and 30 years old, 29% between 30 and 40 years old and 6% above 50 years old.

Extrudate acceptability is shown in Figure 36 and Appendix F. A score of 5 meant the extrudate was not liked nor disliked, therefore values above 5 were considered acceptable. During this evaluation all samples were rated acceptable for shape, hardness and flavor. Regarding shape, FGM had the highest score followed by QPM and HPC. This could be because FGM had lower bulk density and higher apparent volume followed by QPM and HPC. Shape acceptability was directly related to apparent volume and negatively related to bulk density. Also FGM had a more homogeneous appearance compared to QPM and HPC.

All samples acceptable hardness. FGM had the highest score followed by HPC and QPM. FGM melted easier in the mouth while HPC was crunchier. Hardness acceptability was not related to objective texture evaluation (Chapter VII). In the objective hardness evaluation HPC was the hardest followed by QPM and FGM. In the subjective evaluation FGM had the highest score but it was followed by HPC and QPM. Therefore there is a factor affecting hardness acceptability besides the force required to break the extrudate. This factor could be the number of force peaks during breakage of the extrudate. In the objective evaluation, FGM had more peaks followed by HPC and QPM (Chapter VII) which agrees with the subjective hardness acceptability. QPM required greater force to fracture the product on first bite compared to FGC which fractured easier (Table XXXI). This does not agree with the objective hardness evaluation.

In terms of flavor, even though all samples were flavored the same, panelist could detect a difference between QPM decorticated and FGM decorticated. Similar results were found by Acosta-Sanchez (2003), in this experiment all the sorghum extrudates used the same flavoring but the least expanded extrudates had lower scores than the more expanded extrudates. In both experiments untrained panelists evaluated the extrudates, therefore extrudate texture and appearance might have influenced flavor acceptability. Also, the surface area of the products were different, so the flavoring could have been more concentrated in less expanded extrudates.

The degree of adhesiveness, described as the ease of removing the chewed samples from one's teeth, was not significantly affected by corn variety nor decortication level. Texture of snack products is one of the most important characteristics affecting consume acceptance (Suknark et al. 1998), and is perceived by the consumer as an indicator of food quality (Lawless and Heymann 1998). No difference (P < 0.05) was detected between extrudates from decorticated and non-decorticated grain (Table XXXI). Therefore it is feasible to produce extrudates with increased nutritional value and avoiding 10% grain loss during decortication without affecting the consumer acceptability.

Conclusion

Extrudates from decorticated and non-decorticated coarse meal from QPM, FGM and QPM were evaluated for shape, hardness and flavor acceptability and for degree of crispiness and adhesiveness. All samples were judged acceptable for shape, hardness and flavor since all values were above a 5 score. FGM was more acceptable than QPM and HPC. Panelists were not able to perceive any difference in adhesiveness among corn varieties nor decortication level. Panelists were not able to detect a difference between extrudates from decorticated and non decorticated grain.

Extrudates from non decorticated grain can be produced without affecting consumer acceptance. Snack producer could profit from extruding non-decorticated grain, reducing grain loss during decortication process. Health snack producers could benefit by producing a snack with lower carbohydrate and greater fiber, protein and fat. QPM can be used to produce acceptable extruded products such as snacks, break fast cereals or grind it into a porridge with increased protein quality.

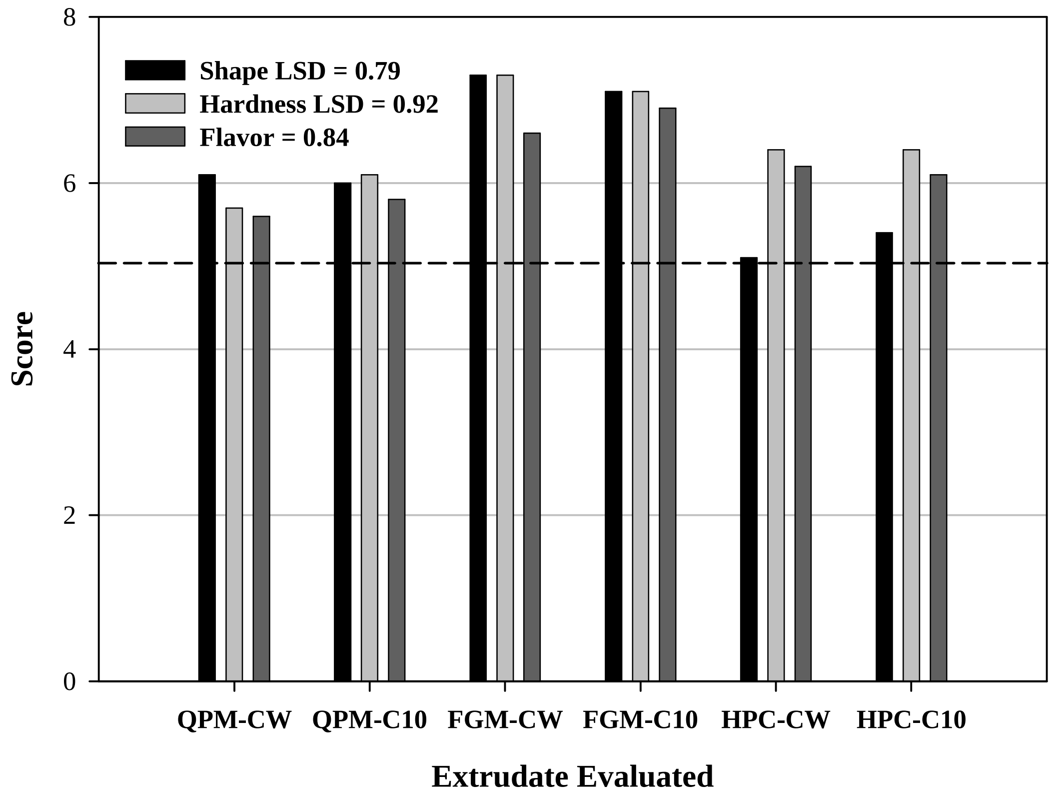

Fig. 36. Sensory properties of QPM, FGM and HPC for shape, hardness and flavor evaluated by 30 untrained panelist. 1= Dislike extremely 5= Neither like nor dislike and 9=like extremely. Doted line = neither like nor dislike

TABLE XXX
Subjective Evaluation of Extrudate Texture [a].

SAMPLE	Crispiness[c]	Adhesiveness[d]
QPM-CW	4.3 b	4.3 a
QPM-C10	4.1 b	4.2 a
FGM-CW	3.4 a	3.4 a
FGM-C10	3.1 a	4.0 a
HPC-CW	3.8 b	4.2 a
HPC-C10	3.9 b	4.0 a
LSD[b]	**0.87**	**0.88**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Ease of fracture and crumble of the product into small pieces after the first bite. 1=Very easy, 5=Neither easy nor difficult and 9=Very difficult.
[d] Ease of remove the product from the teeth. 1= Very easy, 5=Neither easy nor difficult and 9=Very difficult.

TABLE XXXI
Sensory Evaluation for Decorticated and Non-decorticated Extrudates from Quality Protein Maize, Food Grade Maize and High Protein Corn[a]

Sample[c]	Shape	Hardness	Flavor	Crispiness	Adhesiveness
Decorticated	6.17 [a]	6.53 [a]	6.29 [a]	6.77 [a]	5.98 [a]
Non-decorticated	6.15[a]	6.46 [a]	6.15 [a]	6.45 [a]	5.94 [a]
LSD[b]	**0.45**	**0.53**	**0.49**	**0.50**	**0.51**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for means separation.
[c] Average from the three corn varieties.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Physical and chemical properties from QPM, FGM and HPC were excellent for alkaline cooking and dry milling. QPM had test weight, density and kernel size similar to FGM. QPM kernel size was larger than previously reported. QPM protein quality and quantity was superior to FGM since it had 45% more lysine and 38% more tryptophan. HPC had the largest kernel size with density and test weight similar to FGM. Even though HPC usually contains 1-2% points more protein than FGM grown under similar conditions, it had the lowest protein content. Because corn samples in this experiment were not from the same location, differences in environment and growing conditions affected protein content.

QPM, FGM and HPC grains were processed successfully into nixtamal, masa and tortillas. During alkaline cooking, HPC absorbed water faster than QPM and FGM. White QPM required shorter cooking time with reduced dry matter losses compared to FGM. All corn varieties had excellent pericarp removal at the optimum cooking time. The slower pericarp removal in QPM may explain its lower dry matter losses during alkaline cooking. Shorter cooking time and low dry matter losses could be advantageous to tortilla producers by decreasing energy, sewage costs and dry matter losses. Tortillas from QPM had better pliability and rollability during storage compared to FGM and HPC. QPM has promising properties and might produce a tortilla with longer shelf stability with significantly improved nutritional value. These observations will require further confirmation in additional experiments. HPC tortillas had lower rupture force during storage. Thus, HPC has the potential to produce a softer tortilla but further research is needed.

QPM, FGM and HPC were successfully processed into corn meal using a short scale dry milling system. QPM produced more coarse meal with greater fat content compared to

FGM. Meal from the three corn varieties had greater fat, protein and fiber content compared to commercial corn meal. The improved nutritional value of QPM was retained during dry milling. Coarse meal from decorticated and non-decorticated QPM had 72% and 45% more lysine, respectively, compared to coarse meal from decorticated and non-decorticated FGM. Non-decorticated meal had greater protein, fiber and fat content, and lower carbohydrate content compared to decorticated meal. The short scale milling system used in this experiment produced a meal with increased nutritional value, and greater yields compared to degermination systems.

QPM extruded faster than FGM and HPC. FGM required higher specific mechanical energy than QPM. Extrudates from FGM had the lowest bulk density followed by QPM and HPC. Extrudates from HPC were crunchy while FGM extrudates were more crispy. HPC extrudates had higher radial expansion than QPM extrudates but were shorter in length. Lysine content in QPM was not affected by extrusion, it is possible to produce a direct expanded snack from QPM with improved nutritional value.

Decorticated and non-decorticated extrudates had acceptable for shape, hardness and flavor, according to a sensory evaluation. Among corn varieties extrudates from FGM, were preferred. Panelists were not able to detect any differences between extrudates from decorticated and non decorticated grain. Snack producers could profit by extruding ground whole grain, which would have appeal to health conscious consumers desiring the goodness of whole grain. QPM can be used to produce acceptable extruded products such as snacks, break fast cereals or instant porridges with increased protein quality.

QPM is an excellent option for alkaline cooking, dry milling and extrusion processing. QPM has great potential for processing into foods in developing countries were maize is a staple. It has excellent processing properties and increases significantly the nutritional value. The new QPM varieties have processing properties equal to standard food grade corn.

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APPENDIX A

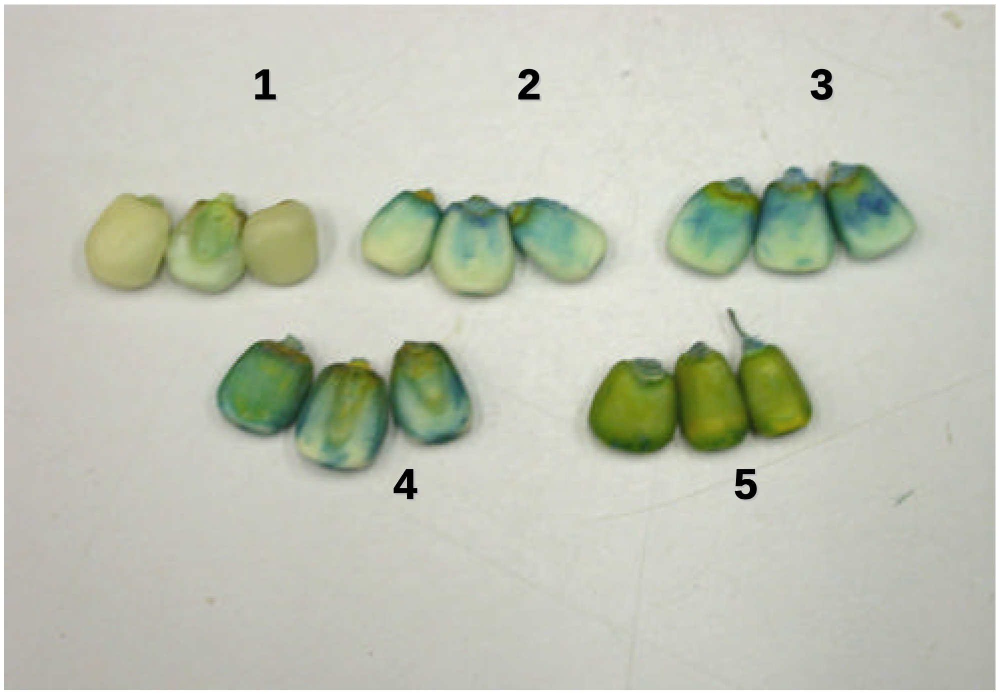

Fig. 37. Scale used as standard during the subjective pericarp removal of the nixtamal.

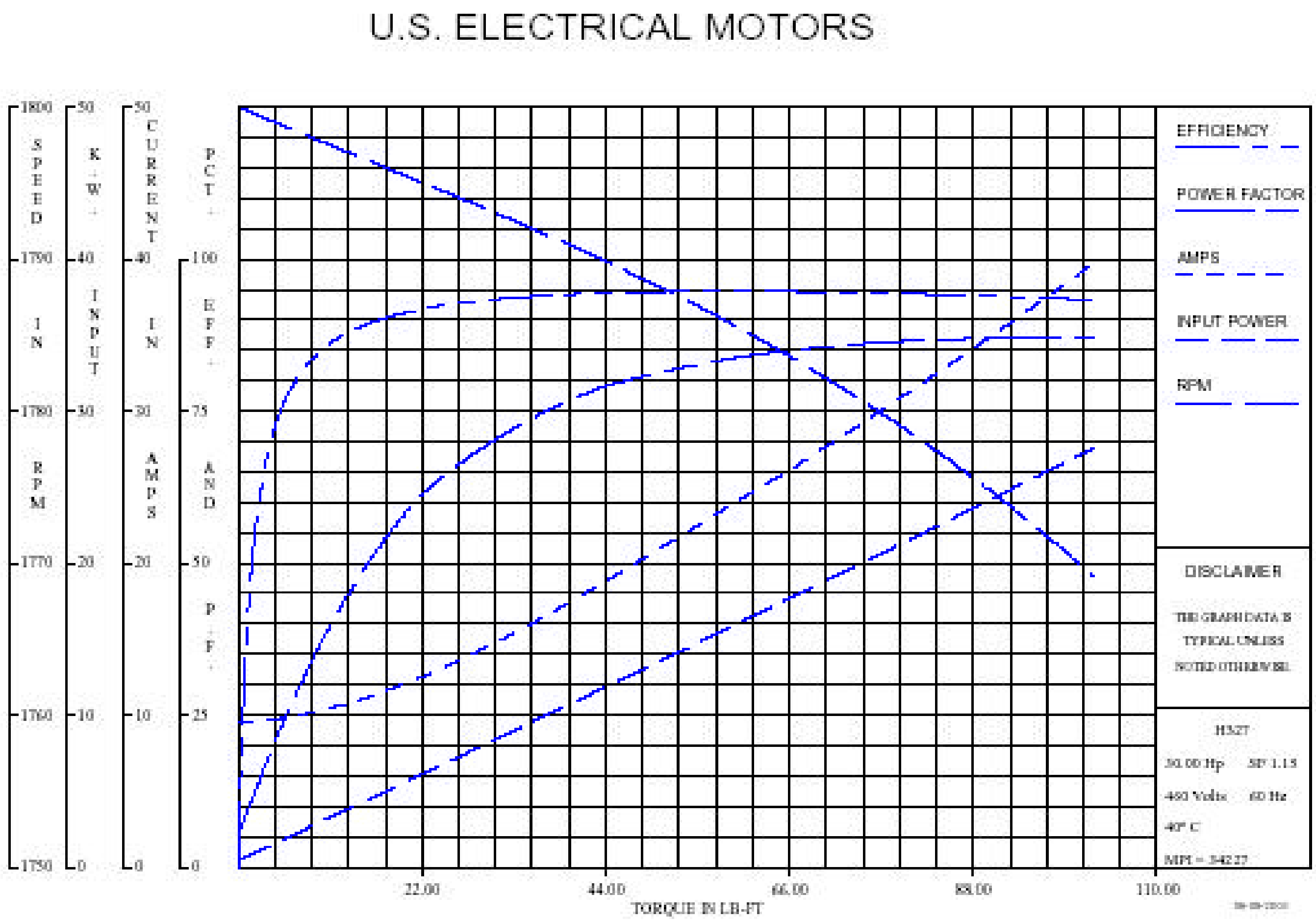

Fig. 38. Conversion table from generated by EMERSON/US Motors for a 460 volts, 60 Hz and 30 Hp motor.

INSTRUCTIONS: Please circle the number that best fits your description

SHAPE APPEARANCE: How do you like its shape and size?

1	2	3	4	5	6	7	8	9
Dislike extremely				Neither like of dislike			Like extremely	

HARDNESS How does it feel at the first bite?

1	2	3	4	5	6	7	8	9
Dislike extremely				Neither like of dislike			Like extremely	

CRISPINESS Does it fracture and crumble into small pieces after the first bite?

1	2	3	4	5	6	7	8	9
Very easy				Neither easy nor difficult				Very difficult

ADHESIVENESS How easy does it remove from the teeth?

1	2	3	4	5	6	7	8	9
Very easy				Neither easy nor difficult				Very difficult

FLAVOR How do you like the flavor?

1	2	3	4	5	6	7	8	9
Dislike extremely				Neither like of dislike			Like extremely	

Fig. 39. Taste panel form used for each sample during the sensory evaluation.

APPENDIX B

TABLE XXXII
Physical Properties of Maize Samples[a]

Sample[c]	TKW[a]	Density	Hardness	Test weight	
	g	g/mL	% Removal	lb/bu	kg/hL
Y-FGM	335.1 b	1.328 c	47.3 e	61.1 d	78.6 d
W-FGM 1	335.0 b	1.348 a	44.1 f	62.6 a	80.4 a
W-FGM 2	319.1 def	1.305 ef	50.1 bc	60.7 ef	78.0 ef
Y-QPM 1	327.6 bcd	1.312 de	49.9 c	61.5 bc	79.0 bc
Y-QPM 2	324.5 cd	1.304 f	49.4 cd	61.6 b	79.3 b
Y-QPM 3	331.2 bc	1.309 def	52.0 a	60.5 f	77.8 f
W-QPM 1	310.1 f	1.316 d	49.1 cd	61.5 b	79.2 b
W-QPM 2	325.2 cd	1.302 f	51.4 ab	59.2 h	76.1 h
W-QPM 3	315.0 ef	1.337 b	46.8 e	59.8 g	76.9 g
W-HPC	367.5 a	1.313 de	48.1 de	61.2 cd	78.7 cd
LSD[b]	**9.3**	**0.007**	**1.43**	**0.31**	**0.40**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

APPENDIX C

TABLE XXXIII
Effect of Alkaline-Cooking Time on Nixtamal Moisture and Dry Matter Losses (DML)[a]

Sample[d]	**Pericarp removal[c]**	**0 min**		**15 min**		**30 min**		**45 min**	
		Moisture (%)	**DML (%)**	**Moisture (%)**	**DML (%)**	**Moisture (%)**	**DML (%)**	**Moisture (%)**	**DML (%)**
Y-FGM	1.2 [c]	44.7 [d]	4.1 [a]	49.7 [c]	5.1 [cd]	53.0 [bc]	5.2 [c]	56.0 [bc]	8.6 [ab]
W-FGM 1	1.2 [c]	44.4 [d]	4.2 [a]	49.5 [c]	5.8 [ab]	50.5 [de]	7.4 [ab]	52.7 [e]	9.0 [a]
Y-QPM 1	3.7 [a]	44.6 [d]	3.1 [b]	47.4 [d]	3.2 [e]	49.2 [ef]	3.5 [d]	55.3 [bcd]	8.3 [ab]
Y-QPM 2	4.0 [a]	45.5 [d]	3.0 [b]	48.7 [c]	3.7 [e]	50.9 [d]	3.8 [d]	55.4 [bcd]	8.8 [ab]
Y-QPM 3	3.7 [a]	45.3 [d]	3.0 [b]	46.8 [d]	4.4 [d]	48.5 [f]	4.7 [c]	54.4 [c]	8.2 [ab]
W-QPM 1	4.0 [a]	49.1 [a]	2.8 [b]	52.1 [b]	5.5 [c]	53.8 [eb]	6.3 [b]	56.6 [a]	8.9 [ab]
W-QPM 2	4.0 [a]	48.5 [a]	2.5 [b]	51.5 [b]	5.7 [bc]	51.9 [cd]	7.8 [a]	58.1 [a]	8.9 [ab]
W-QPM 3	2.0 [b]	47.8 [bc]	1.9 [c]	51.1 [b]	5.5 [c]	52.6 [bc]	6.5 [b]	54.8 [bcd]	7.5 [b]
W-HPC	2.3 [b]	46.8 [c]	3.3 [b]	53.2 [a]	6.6 [a]	54.4 [e]	8.3 [a]	55.9 [bcd]	9.7 [a]
LSD^{b}_{grain}	**0.51**	**1.1**	**0.7**	**1.1**	**1.4**	**1.5**	**0.9**	**1.6**	**1.5**
Mean	**2.9**	**46.32**	**3.23**	**49.99**	**5.15**	**51.36**	**5.84**	**54.98**	**7.70**
LSD_{time}	**---**				**1.24**				
LSD_{DML}	**---**				**1.18**				

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Pericarp removal evaluation was done cooking the samples 20 min and without steeping.
[d] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

APPENDIX D

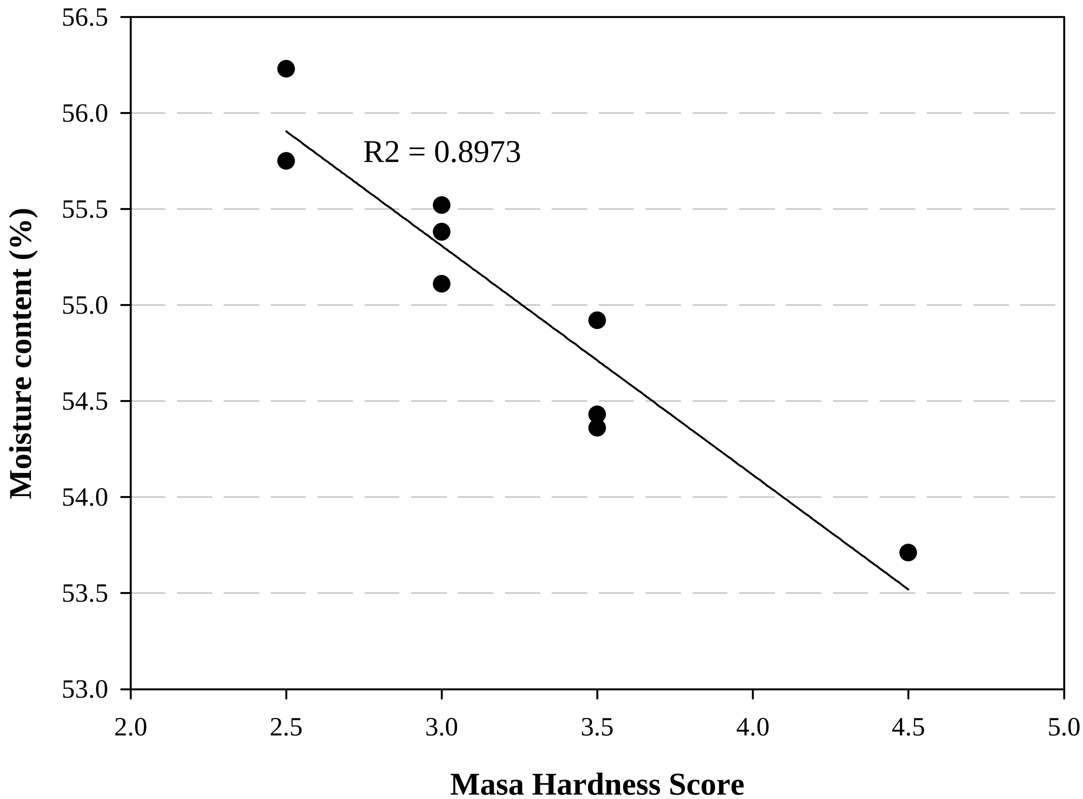

Fig. 40. Effect of masa moisture in masa hardness. Score: 1 = low, 3 = intermediate and to 5 = high.

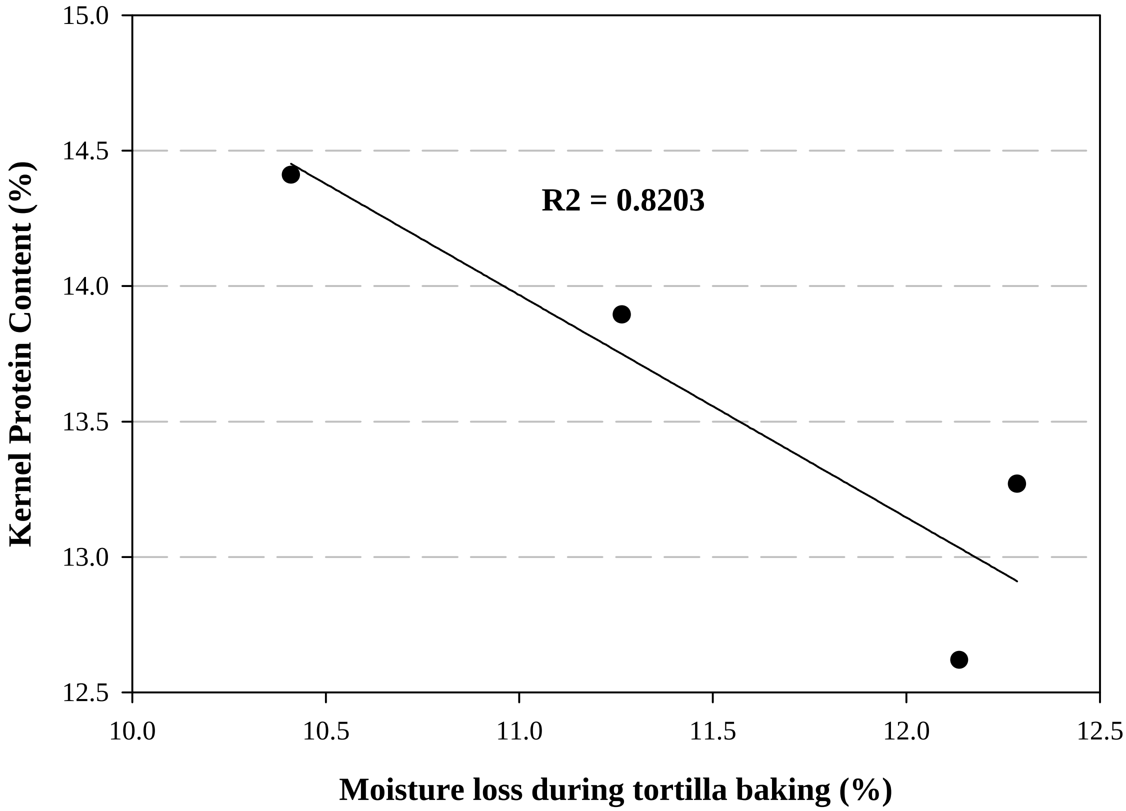

Fig. 41. Effect of kernel protein content on moisture loss during tortilla baking. Moisture loss was obtained by subtracting tortilla moisture from masa moisture. Average values from food grade maize, yellow quality protein maize, white quality protein maize and high protein corn were used.

TABLE XXXIV
Rollability of the Tortilla Through Storage Time

SAMPLE[c]	Rollability				
	0.5 hr	**6 hr**	**24 hr**	**72 hr**	**120 hr**
Y-FGM	5.0 [a]	5.0 [a]	5.0 [a]	4.8[a]	3.6 [f]
Y-QPM 1	5.0 [a]	5.0 [a]	5.0 [a]	4.7 [a]	4.4 [cd]
Y-QPM 2	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]
Y-QPM 3	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	4.8 [ab]
W-FGM 1	5.0 [a]	5.0 [a]	5.0 [a]	4.7 [a]	4.2 [de]
W-QPM 1	5.0 [a]	5.0 [a]	5.0 [a]	4.8 [a]	4.6[bc]
W-QPM 2	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]
W-QPM 3	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]
W-HPC	5.0 [a]	5.0 [a]	5.0 [a]	4.2 [b]	4.0 [e]
LSD[b]	**0**	**0**	**0**	**0.40**	**0.31**
Mean	**5**	**5**	**5**	**4.8**	**4.5**
LSD_{time}			**0.19**		

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

TABLE XXXV
Pliability of the Tortilla Through Storage Time

SAMPLE[c]	Pliability				
	0.5 hr	**6 hr**	**24 hr**	**72 hr**	**120 hr**
Y-FGM	5.0 [a]	5.0 [a]	4.5[bc]	4.2 [ab]	3.7 [cd]
Y-QPM 1	5.0 [a]	5.0 [a]	4.7[ab]	4.4 [ab]	4.3 [ab]
Y-QPM 2	5.0 [a]	5.0 [a]	4.4[c]	4.2 [ab]	3.3 [d]
Y-QPM 3	5.0 [a]	5.0 [a]	4.7[ab]	4.3 [ab]	4.1 [abc]
W-FGM 1	5.0 [a]	5.0 [a]	4.5[b]	3.5 [c]	2.8 [e]
W-QPM 1	5.0 [a]	5.0 [a]	4.5[bc]	4.2 [b]	4.0 [bc]
W-QPM 2	5.0 [a]	5.0 [a]	4.7[ab]	4.5 [ab]	4.4 [ab]
W-QPM 3	5.0 [a]	5.0 [a]	5.0[a]	4.6 [a]	4.6 [a]
W-HPC	5.0 [a]	5.0 [a]	4.5[bc]	4.5 [ab]	3.7 [cd]
LSD[b]	**0**	**0**	**0.31**	**0.44**	**0.48**
Mean	**5**	**5**	**4.61**	**4.27**	**3.9**
LSD_{time}			**0.14**		

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Y = yellow; W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

TABLE XXXVI
Rupture Force 1-D Extensibility Objective Evaluation of Tortilla from Food Grade Maize, Quality Protein Maize and High Protein Corn[a]

SAMPLE	Rupture force (N)				
	0.5 hr	**6 hr**	**24 hr**	**72 hr**	**120 hr**
Y-FGM	7.59 ^{b}	10.6 ^{d}	12.7 ^{f}	13.9 ^{de}	14.8 ^{d}
W-FGM 1	3.44 ^{ef}	11.4 ^{c}	14.3 ^{de}	15.1 ^{cd}	16.7 ^{bc}
FGM $\bar{X}$	**5.52 ^{AB}**	**11.0 ^{B}**	**13.5 ^{B}**	**14.5 ^{B}**	**15.8 ^{AB}**
Y-QPM 1	8.19 ^{a}	12.2 ^{abc}	18.0 ^{a}	19.4 ^{a}	20.0 ^{a}
Y-QPM 2	5.82 ^{c}	11.8 ^{abc}	13.3 ^{ef}	12.8 ^{e}	14.8 ^{d}
Y-QPM 3	4.51 ^{d}	10.5 ^{d}	16.3 ^{b}	15.9 ^{bc}	16.8 ^{bc}
YQPM $\bar{X}$	**6.18 ^{A}**	**11.5 ^{AB}**	**15.9 ^{a}**	**16.1 ^{AB}**	**17.2 ^{A}**
W-QPM 1	4.73 ^{d}	12.3 ^{ab}	15.4 ^{bcd}	16.9 ^{b}	18.0 ^{b}
W-QPM 2	4.89 ^{d}	12.4 ^{a}	14.7 ^{cd}	15.3 ^{bc}	16.8 ^{bc}
W-QPM 3	3.88 ^{e}	11.5 ^{bc}	16.0 ^{bc}	16.3 ^{bc}	16.5 ^{bc}
W-QPM $\bar{X}$	**4.51 ^{BC}**	**12.0 ^{A}**	**15.4 ^{a}**	**16.2 ^{A}**	**17.1 ^{A}**
W-HPC	3.06 ^{f}	7.7 ^{e}	12.5 ^{f}	14.5 ^{d}	14.0 ^{d}
HPC $\bar{X}$	**3.06 ^{C}**	**7.7 ^{C}**	**12.5 ^{B}**	**14.5 ^{B}**	**14.1 ^{B}**
LSD[b]	**0.53**	**1.43**	**1.29**	**1.4**	**1.6**
LSD $\bar{X}$	**1.55**	**0.79**	**1.6**	**2.02**	**1.9**
Mean	**5.12**	**11.16**	**14.81**	**15.74**	**16.33**
LSD$_{time}$			**0.86**		

[a] Means in the same column and the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.

TABLE XXXVII
Rupture Distance 1-D Extensibility objective Evaluation of Tortilla from Food Grade Maize, Quality Protein Maize and High Protein Corn[a]

SAMPLE	Rupture distance (mm)				
	0.5 hr	**6 hr**	**24 hr**	**72 hr**	**120 hr**
Y-FGM	5.6 [f]	2.6 [ab]	1.9 [c]	1.8 [b]	1.3 [d]
W-FGM 1	6.2 [def]	2.2 [b]	2.1 [c]	1.8 [b]	1.9 [ab]
FGM $\bar{X}$	**5.9 [B]**	**2.4 [A]**	**2.0 [B]**	**1.8 [A]**	**1.6 [A]**
Y-QPM 1	6.0 [ef]	3.0 [a]	2.2 [ab]	2.3 [a]	1.8 [bc]
Y-QPM 2	8.0 [bc]	3.0 [a]	2.3 [ab]	2.1 [ab]	1.9 [ab]
Y-QPM 3	7.2 [cde]	2.2 [b]	2.5 [a]	1.8 [b]	1.4 [cd]
Y-QPM $\bar{X}$	**7.1 [AB]**	**2.8 [A]**	**2.4 [A]**	**2.1 [A]**	**1.7 [A]**
W-QPM 1	12.3 [a]	3.0 [a]	2.3 [ab]	1.9 [ab]	2.2 [a]
W-QPM 2	5.6 [f]	2.8 [ab]	2.1 [abc]	2.0 [ab]	1.6 [bcd]
W-QPM 3	9.4 [b]	2.8 [ab]	2.3 [ab]	2.0 [ab]	2.0 [ab]
W-QPM $\bar{X}$	**9.1 [A]**	**2.9 [A]**	**2.3 [A]**	**2.0 [a]**	**1.9 [A]**
W-HPC	7.6 [cd]	2.7 [ab]	2.1 [abc]	2.0 [ab]	1.9 [bc]
HPC $\bar{X}$	**7.6 [EF]**	**2.8 [A]**	**2.1 [AB]**	**2.0 [a]**	**1.7 [A]**
LSD[b]	**1.4**	**0.67**	**0.35**	**0.39**	**0.39**
LSD $\bar{X}$	**2.1**	**0.52**	**0.25**	**0.31**	**0.37**
Mean	**7.55**	**2.72**	**2.21**	**1.96**	**1.74**
$\mathbf{LSD_{time}}$			**0.49**		

[a] Means in the same column and the same font followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.

APPENDIX E

TABLE XXXVIII
Chemical Composition of Food Grade Maize, Quality Protein Maize and High Protein Corn Used During Extrusion[ab]

Sample[e]	Moisture (%)	Protein[d] (%)	Fat (%)	Fiber (%)
W-FGM 2	11.4 [b]	11.49 [a]	3.25 [b]	2.58 [a]
W-QPM 3	13.2 [a]	11.54 [a]	4.15 [a]	2.37 [c]
W-HPC	13.4[a]	10.41 [b]	3.58 [ab]	2.51 [b]
LSD[c]	**0.5**	**0.31**	**0.58**	**0.06**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] Results are expressed on dry weight basis.
[c] LSD = Least significant difference for means separation.
[d] Crude protein = N X 6.25.
[e] W = white; FGM = food grade maize; QPM = quality protein maize; HPC = high protein corn.

TABLE XXXIX
Corn Meal Fractions Yield [a]

SAMPLE	Coarse[c]	Medium[d]	Fine[e]
	< No. 10 > No. 20	**< No. 20 >No.40**	**<No.40**
FGM Non-decorticated	52.4 a	23.0 a	24.6 a
FGM 10% decorticated	45.7 b	20.6 c	25.02 a
QPM Non-decorticated	54.3 a	23.3 a	22.3 b
QPM 10% decorticated	46.8 b	21.1 b	22.2 b
HPC Non-decorticated	53.2 a	22.7 a	24.0 a
HPC 10% decorticated	45.8 b	19.3 b	23.6 ab
LSD[b]	**1.99**	**1.03**	**1.56**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Meal through US sieve No. 10 and over sieve No. 20.
[d] Meal through US sieve No. 20 (850 µm) and over sieve No. 40 (425 µm) .
[e] Meal through US sieve No. 40 (425 µm) . This fraction was discarded.

TABLE XL
Food Grade Maize, Quality Protein Maize and High Protein Corn Meal Color[a]

MEAL SAMPLE	Color[c]		
	L*	**a***	**b***
FGM-CD	77.7 [e]	-.083 [de]	13.8 [f]
FGM-CW	75.2 [g]	-0.29 [c]	15.5 [e]
FGM-MD	83.4 [ab]	-1.38 [g]	11.2 [g]
FGM-MW	82.5 [b]	-1.21 [fg]	11.2 [g]
QPM-CD	78.6 [d]	-0.65 [d]	14.2 [f]
QPM-CW	76.6 [f]	0.25 [b]	16.9 [b]
QPM-MD	77.6 [e]	-0.66 [d]	14.2 [f]
QPM-MW	80.6 [c]	-0.60 [d]	15.6 [de]
HPC-CD	78.4 [de]	0.03 [b]	19.9 [a]
HPC-CW	76.3 [f]	0.61 [a]	19.9 [a]
HPC-MD	83.9 [a]	-0.94 [e]	16.0 [cd]
HPC-MW	82.5 [b]	-0.96 [ef]	16.4 [bc]
LSD[b]	**0.9**	**0.24**	**0.5**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue

TABLE XLI
Corn Meal Composition from Decorticated and Non-decorticated Food Grade Maize (FGM), Quality Protein Maize (QPM) and High Protein Corn (HPC)[a]

SAMPLE	Moisture (%)	Protein[c d] (%)	Fiber[d] (%)	Fat[d] (%)
FGM-CD	14.2 a	11.6 d	0.84 g	2.3 g
FGM-CW	14.2 a	11.7 d	2.7 a	2.2 g
FGM-MD	12.5 de	12.0 c	1.3 e	4.0 b
FGM-MW	12.8 c	12.7 a	2.1 c	3.7 c
QPM-CD	13.6 b	11.1 e	1.1 f	3.1 de
QPM-CW	12.3 ef	11.0 f	2.3 b	3.0 de
QPM-MD	12.4 e	12.1 c	1.5 d	4.2 b
QPM-MW	11.7 g	12.3 b	2.1 c	4.6 a
HPC-CD	12.7 cd	10.6 g	1.3 de	2.8 ef
HPC-CW	13.7 b	10.4 h	2.8 a	3.2 d
HPC-MD	12.7 cd	10.8 g	1.5 de	3.9 c
HPC-MW	12.0 fg	11.0 ef	2.2 bc	3.9 c
LSD[b]	**0.35**	**0.21**	**0.17**	**0.27**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] % of protein=N x 6.25
[d] Expressed in dry weight basis.

TABLE XLII
Processing Conditions During Extrusion of Food Grade Maize, Quality Protein Maize and High Protein Corn[a]

SAMPLE	Energy (Amps)	Feed Rate (g/sec)	SME[c] (KJ/Kg)
FGM-CD	31.5 [a]	38.6	104 [a]
FGM-CW	31 [a]	38.3	103 [a]
FGM-MD	26.7 [cd]	32.3	101 [ab]
FGM-MW	22.3 [e]	24.9	102 [a]
QPM-CD	32.6 [a]	42.5	99 [abc]
QPM-CW	32.1 [a]	39.4	105 [a]
QPM-MD	28.6 [b]	38.4	93 [cde]
QPM-MW	28.5 [bc]	37.7	94 [bcd]
HPC-CD	31.9 [a]	39.4	104 [a]
HPC-CW	28.1 [bc]	39.0	87 [de]
HPC-MD	27.8 [bc]	38.0	92 [cde]
HPC-MW	25.1 [d]	35.4	85 [e]
LSD[b]	**1.82**	**--**	**7.53**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] Specific mechanical energy. SME= (Torque) (screw speed) / Feed rate.

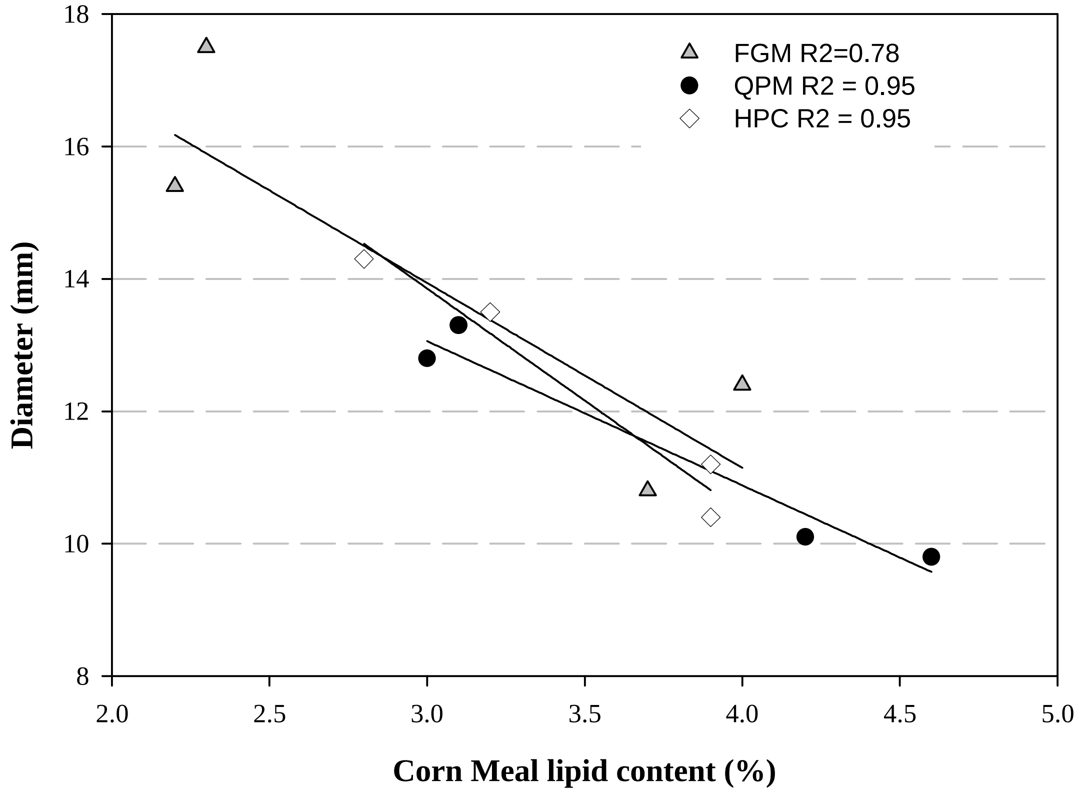

Fig. 42. Effect of corn meal lipid content on extrudate diameter from food grade maize (FGM), quality protein maize (QPM) and high protein corn (HPC).

TABLE XLIII
Food Grade Maize, Quality Protein Maize and High Protein Corn Extrudate Diameter, Length, Apparent Volume and Radial Expansion[a]

SAMPLE	Diameter (mm)	Lenght (mm)	Apparent volume[c] (mm^3)	Radial expansion[d]
FGM-CD	17.5 a	37.5 a	9067 a	38.3 ab
FGM-CW	15.4 b	33.9 bc	6376 b	43.3 a
FGM-MD	12.4 e	37.3 ab	4588 cd	29.6 de
FGM-MW	10.8 fg	34.6 cd	3059 ef	17.9
QPM-CD	13.3 d	36.8 ab	5122 c	31.6 cd
QPM-CW	12.8 de	39.5 a	5064 c	27.9 de
QPM-MD	10.1 gh	34.0 bc	2762 ef	11.73 h
QPM-MW	9.8 h	32.0 cde	2439 f	12.4 gh
HPC-CD	14.3 c	30.0 def	4775 cd	31.5 cd
HPC-CW	13.5 d	29.2 ef	4167 d	35.7 bc
HPC-MD	11.2 f	34.0 bc	2412 f	18.7 f
HPC-MW	10.4 gh	28.2 e	3387 e	24.8 e
LSD[b]	**0.69**	**3.4**	**726**	**5.5**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for means separation.
[c] Apparent volume = π (extrudate diameter / 2)^2 (extrudate length).
[d] Radial expansion = extrudate diameter / die diameter.

TABLE XLIV
Food Grade Maize, Quality Protein Maize and High Protein Corn Extrudate Bulk Density, Force Peak and Number of Peaks[a]

SAMPLE	Bulk density (g/mL)	Force Peak[c] (g)	Number of peaks[d]
FGM-CD	0.092 k	1314 g	38.3 ab
FGM-CW	0.111 j	1766 f	43.3 a
FGM-MD	0.158 g	2542 de	29.6 de
FGM-MW	0.214 e	3421 b	17.9
QPM-CD	0.132 i	2991 c	31.6 cd
QPM-CW	0.142 h	2919 cd	27.9 de
QPM-MD	0.227 a	3721 ab	11.73 h
QPM-MW	0.232 d	3462 b	12.4 gh
HPC-CD	0.174 f	3612 b	31.5 cd
HPC-CW	0.176 f	2390 e	35.7 bc
HPC-MD	0.240 c	4123 a	18.7 f
HPC-MW	0.263 b	3526 b	24.8 e
LSD[b]	**0.002**	**413**	**5.5**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for means separation.
[c] Force peak required to break the extrudate.
[d] Number of peak force required to break the extrudate.

TABLE XLV
Food Grade Maize, Quality Protein Maize and High Protein Corn Extrudate Color[a]

EXTRUDATE SAMPLE	Color[c]		
	L*	**a***	**b***
FGM-CD	87.3 [a]	-1.2 [abc]	13.7 [i]
FGM-CW	85.9 [fg]	-1.0 [abc]	14.9 [g]
FGM-MD	86.6 [c]	-0.5 [a]	15.6 [e]
FGM-MW	85.7 [gh]	-1.2 [bc]	16.1 [d]
QPM-CD	87.2 [ab]	-1.6 [c]	14.5 [h]
QPM-CW	85.6 [h]	-0.6 [ab]	14.7 [g]
QPM-MD	86.3 [d]	-1.4 [c]	15.2 [f]
QPM-MW	86.0 [ef]	-1.2 [abc]	16.7 [c]
HPC-CD	87.0 [b]	-1.5 [c]	15.1 [f]
HPC-CW	86.1 [de]	-1.5 [c]	16.9 [b]
HPC-MD	87.2 [a]	-1.5 [c]	16.6 [c]
HPC-MW	86.6 [c]	-1.5 [c]	17.0 [a]
LSD[b]	**0.19**	**0.77**	**0.12**

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] L* = (0 black: 100 white); a* = (+ 60 red: -60 green); b* = (+60 yellow: -60 blue).

APPENDIX F

TABLE XLVI
Food Grade Maize, Quality Protein Maize and High Protein Corn Extrudate Acceptability for Shape, Hardness and Flavor[a]

SAMPLE	Shape[c]	Hardness[c]	Flavor[c]
QPM-CW	6.1 [b]	5.7 [c]	5.6 [c]
QPM-C10	6.0 [b]	6.1 [c]	5.8 [bc]
FGM-CW	7.3 [a]	7.3 [a]	6.6 [ab]
FGM-C10	7.1 [a]	7.1 [ab]	6.9 [a]
HPC-CW	5.1 [c]	6.4 [bc]	6.2 [abc]
HPC-C10	5.4 [bc]	6.4 [bc]	6.1 [abc]
LSD[b]	0.79	0.92	0.84

[a] Means in the same column followed by the same letter are not significantly different at 0.05 level.
[b] LSD = Least significant difference for mean separation.
[c] 1= Dislike extremely 5= Neither like or dislike and 9=like extremely

VITA

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